Land Cover Mapping and Change Analysis at the Tensleep Preserve in Wyoming

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Land Cover Mapping and Change Analysis at the Tensleep Preserve in Wyoming

By

Tyler Grupa

2016

A Thesis submitted in Partial Fulfillment of the Requirements for the Degree of

Masters of Science

In

Geography

Minnesota State University, Mankato

Mankato, Minnesota

July 2016
April 29, 2016

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This thesis has been examined and approved by the following members of the student’s committee.

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Acknowledgments

I would like to thank my advisor, Dr. Cynthia Miller, for her encouragement, constant support, and enthusiasm. Dr. Miller was on sabbatical and she still made time to help me with this thesis, thank you! A special thanks to Dr. Fei Yuan for the ample guidance and support throughout my thesis processes. The knowledge you shared for this thesis and beyond was extremely helpful and greatly appreciated. Thanks to Dr. Ginger Schmid for the support and guidance during my thesis work.

Thanks to Carol Reedstrom, the Department of Geography, and all its faculty and staff for the friendly atmosphere and professionalism. Thanks to the James F. Goff Geography Graduate Research Endowment, this funding allowed me to collect research data for twenty-one days during the summer of 2013. Also, thanks to Dustin Marlow for providing a Trimble GPS unit in the field.

Finally, I am extremely grateful for the support and positivity from my parents, Brad and Sandy Grupa. Without you both this would not have been possible. Thanks to my girlfriend, Hannah Hiniker, for your continuous support and encouragement.
Abstract

Mapping land cover and land cover change are important, especially for land managers who protect natural lands and generate restoration projects. Accurate land cover assessment of rangelands can be difficult because the spectral difference between plant species may be minimal. The goal of this research is to map the land cover in the Tensleep Preserve and highlight change that has occurred over the past twenty-three years using the Feature Analyst extension. The land cover change map will highlight significant changes and Feature Analyst will accurately identify different land covers using historical aerial photographs and ground truthing data collected in 2013.

Owned by the Nature Conservancy, the Tensleep Preserve includes 10,088 acres of mixed ecosystems in the foothills of Wyoming’s Big Horn Mountains and has a unique floral and faunal history. Ungulates use the property as a corridor for migration routes and Canyon Creek provides fresh water along a twelve mile stretch. This rangeland is rich in biodiversity because its remarkable topography offers abundant habitats. Understanding the land cover trends that have occurred over time is needed to restore natural habitats and protect endemic plant species. The final analysis will document change over the past two decades and give management a decision making tool for current and future projects.
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1. Introduction

The Tensleep Preserve

In June 2010, the Minnesota State University (MNSU), Mankato issued minivan slowly kicked up dust from the dirt road that lead to the Tensleep Preserve tent camp. Entering the Big Horn Mountains from the west, into the foothills of the mountain at the Tensleep Preserve, it was easy to see that this land was pristine and is bursting with aesthetic value. The Field Ecology summer class traveled from Yellowstone National Park, to the Tensleep Preserve in Ten Sleep, Wyoming. The class camped, cooked meals, hiked, and were taught field ecology skills by Dr. John Krenz and Dr. Christopher Ruland. Trey Davis III, who is the land manager at the preserve and is The Nature Conservancy’s (TNC) Wyoming Land Management Supervisor, led the class on hikes through the preserve. The knowledge he shared in the short time spent with the class was astonishing: pointing and naming plant species with ease, stopping mid-hike and standing still showing how quiet it can be while the soft noises in the distance slowly became noticeable. The passion Trey portrayed and his knowledge about the Tensleep Preserve made an impression on every student in the class. Land preservation and the protection of biodiverse ecosystems simply became a realization for me which is the most important action we can accomplish today.

Fortunately the following summer, I was the awarded the Rangeland Conservation Internship at the Tensleep Preserve. I was able to see firsthand how the preserve operated, conducted my own small land projects, visit other TNC properties and people, and lead eco-hikes to visiting groups to the preserve. During that summer I saw old maps of the preserve, some of which were hand drawn. The numerous old maps, mostly showing the topography and trails, made me realize that an updated map of the preserve would benefit the land manager by mapping the preserve land cover and could assist with stewardship and restoration projects like noxious
weed removal. Even though The Nature Conservancy has a Wyoming Chapter with Geographic Information System (GIS) scientists, it is unclear if the Tensleep Preserve has ever had a land cover analysis completed. The analysis can support restoration projects, help with prevention of invasive plants, and give a tangible example of the condition of the easement managed. The diversity within the canyon creek areas is amazing, and the south facing slope on which the preserve lies holds astonishing natural value which should be protected. The creeks are interesting microclimate region because, unlike the uplands, they are flush with flora and the air is humid and filled with buzzing insects. The uplands at the preserve are semi-arid regions where the grasses and shrubs are plenty, while ponderosa, lodgepole, and limber pines dominate the severe slopes facing north and south. The research goal is to provide Trey with an accurate land cover change analysis of this diverse ecosystem from 1989 to 2012. With this information, the Tensleep Preserve management team can make use of the results by coordinating restoration projects and improving invasive plant removal missions. The study site (Figure 1.1) shows the Tensleep Preserve location and boundary in Wyoming, the elevation in meters, and property features such as streams and Cook’s Vee.

Early that summer, before I went to Wyoming, I had been introduced to GIS by Dr. Fei Yuan. I was fascinated by the science of GIS so I continued taking GIS classes and earned a Certificate in GIScience two years later. Fortunately I was able to combine my two interests of GIS and the preservation of natural landscapes in the Tensleep Preserve into this thesis project. It is my hope the results will be useful to Trey and his team. These two experiences I had through MNSU, Mankato during June of 2010 lead to this thesis project. It is my intention to use computer-based analysis to provide tangible and quantified information to Trey and the Tensleep staff for making executive land management decisions.
The health of the vegetation on the vast, undulating terrain of the Tensleep Preserve is monitored year round by Trey and The Nature Conservancy, so a seasonal remote sensing-based vegetation indices analysis was not performed. Conifers and shrubs are the dominant tree species on the preserve. Trey is an avid skier and hiker, so he has a firsthand look at the conifers and shrubs on the preserve from season to season. However, the movement of the vegetation as land cover change may not be as noticeable on an annual basis because the change would be gradual. GIS analysis accurately map these changes and enable statistical confirmation.

Proper management of transitional vegetation zones in the preserve is also important to maintaining vulnerable ecosystems. The undisturbed down trees are great habitat areas for bees, despite the fact that the decaying vegetation accumulates possible fire fuel. A visiting bee expert hiked the preserve with Trey and made the comment that this area has some of the best bee habitats that he has seen. Other preserves and managed lands would treat the dead trees and debris as a nuisance and make arrangements to have it cleared. However, Trey understands the importance of death and that a dead branch can act as a haven to many different insect species and small mammals. Knowing where these zones are will allow him and his staff to properly manage them to keep the bee populations healthy.

Ungulates use the Tensleep Preserve as a corridor during migration times and multiple sites on the preserve show evidence of ritual gatherings where the ground is fine as salt and surrounding trees have antler scars. This migration haven is important for ungulates because there are few areas that provide space for relatively safe migration. During my introductory visit to the preserve in late spring, Trey showed me Cook’s Vee, an area on the preserve with a dirt road winding through grasslands, sagebrush, lupines, and juniper pines where hundreds of elk rested and grazed in a grassy meadow. Monitoring the vegetation land covers on Cook’s Vee is
vital because it is an area utilized by an abundance of animals and birds, and has large patches of native vegetation such as sagebrush, juniper pines, and grasslands.

The preserve staff has also conducted prescribed burns in the past in a small sagebrush community to minimize ground fuel. A prescribed burn took place in 1999, and as a result today, only standalone sagebrush plants are currently present. The cutoff line where the burn took place is easily identifiable. This area clearly shows the slow recovery time of the sagebrush communities in this area on the preserve. Land cover mapping of this area within the preserve will likewise help the staff monitor the effects in coming years. The prescribed burn area is monitored by the Tensleep Preserve manager. Other areas of land cover change that are unidentified on the preserve could become noticed after analyzing the land cover change map.

1.1 The Nature Conservancy

In 1951, a group of plant ecologists founded The Nature Conservancy (TNC) with the goal of preserving natural lands for scientific use (Kareiva et al. 2014). Over time, this intent became more focused on using science in the service of nature protection (Kareiva et al. 2014). In effect, the Conservancy is building a modern Noah’s ark that protects the remaining natural lands, plants, wildlife, and ecological systems on which our planet depends (Blair 1986). The Nature Conservancy was an early pioneer in the arena of land acquisition and protection, their first property being a 24-ha parcel along the Mianus River Gorge purchased in 1955 (Kareiva et al. 2014). This non-profit conservation organization has more than one million dues-paying members, employs 3,800 staff (including 600 scientists), and controls more than one-fourth of all assets held by 1,754 conservation organizations registered for tax purposes with the U.S. government (Armsworth et al. 2012). In 1970, TNC hired Robert Jenkins as their first scientist and he directed the organization to adapt a systematic method of prioritizing lands for purchase
(Kareiva et al. 2014). The Nature Conservancy uses the term ‘stewardship’ to describe their concept of land management, which emphasizes caring for preserved areas as well as monitoring sites transferred to others such as easements (Blair 1986). Today, the mission of the Conservancy is to “conserve the lands and waters on which all life depends” (The Nature Conservancy 2016).

Another notable aspect of TNC is that they conduct their work with the local communities and businesses to accomplish their conservation goals. Building bridges with the community is extremely important for cooperative conservation efforts for natural land protection. I witnessed this trait as the organization worked with the surrounding ranchers, businesses, and community organizations to meet preservation goals for the Tensleep Preserve. Furthermore, The Nature Conservancy works with other organizations like the Wyoming Game and Fish Department (WGFD) for the expansion of cooperative scientific research. I was able to assist with a trout stream survey at two different locations on the preserve with the WGFD during my internship in the summer of 2011. Though The Nature Conservancy manages natural areas, almost all of the areas are also used for other compatible purposes, which vary from original research to nature study (Blair 1986).
Figure 1.1. The Tensleep Preserve study area in Ten Sleep, Wyoming.
1.2 Land Preservation and Protected Lands

The World Commission on Protected Areas (WCPA) adopted a definition that describes a protected area as “clearly defined geographical space, recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (Dudley 2008). Preserving the natural lands across the world is important to all living things because complex ecosystems depend upon all parts, large or small. Natural areas are in need of detailed land cover change analysis because climate changes can affect ecosystems and native species. When Jenkins became the lead scientist for The Nature Conservancy, the Natural Heritage Programme (an international organization) began to take inventory on plant and animal species and ecological communities (Kareiva et al. 2014). The impact of the human population growth and development across the world has placed stress upon natural areas and delicate ecosystems. All natural resources are important but nothing can survive without clean water because all life depends upon it. Land preservation is often a necessity because of outside pressures like encroaching development (Richardson 2000).

Exceptional places like wetlands, prairies, and mountains are areas which revive fresh water by acting like a filtering system. Mountains hold the source of fresh water in snow packs which melt each spring, and in some areas, year round. This snow melt is important for the survival of species which live in arid or semi-arid regions. Life in arid regions depends on the little precipitation available by developing survival mechanisms to conserve the water and finding a niche in these dry areas. Protected lands also include some of the last frontiers that have unique landscapes characteristics and ecosystem functions (Wang 2012). The Tensleep Preserve is one of these unique landscapes with different ecosystems created by years of
freshwater melting from the Big Horn Mountains. Field-oriented mapping approaches have been implemented in the past for management of protected lands and remote sensing science has profoundly changed and contributed to the practice in land management (Wang 2012).

1.3 Land Cover Mapping

Land cover mapping and monitoring is one of the major applications for observing the Earth using remote sensing data and it is essential for the estimation of land cover change (Rodriguez-Galiano et al. 2012). Traditionally, medium-resolution Landsat images are used because the scenes cover a large area and hold multiple layers which are layered and processed to produce a Digital Number (DN). The DN is a pixel value that represents the ground spectral value. Furthermore, traditional classification methods produce a classified image using the DNs for each pixel which does not include spatial context. There are issues with per-pixel classification methods that reduce the quality of the land cover classification, so an object-based classification method was used in this research for land cover classification at the Tensleep Preserve. An object-based classification aggregate image pixels into spectrally homogenous image objects then classifies the individual objects using an image segmentation algorithm (Liu and Xia 2010). This process is better than per-pixel classification methods because pixels from an entire object are congregated and classified.

Understanding the past and current land covers within natural areas can provide insight toward the condition, inclinations and possible changes in vegetation. The data acquired from remote sensing satellites provides an opportunity to acquire information about the land cover at varying resolutions and has been widely used for change detection studies (Hussain et al. 2013). This land cover information is valuable to land managers because prevention and restoration projects take time and money. Detailed land cover change maps can help prioritize decisions,
and therefore save time and money. Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh 1989).

The remote sensing and GIS combination is a powerful tool for land cover analysis. The combination has greatly improved in recent years, especially with object recognition software which separates features from a digital image. Since the early 1970s satellites have been taking digital remote sensing images of Earth’s surface (Goodchild 1994). Over the past few decades the use of remote sensing imagery to classify the land surface has become widespread in GIScience. Satellites have been circling Earth for nearly five decades collecting visual information in a consistent temporal method. The spectral representation of each pixel in a scene or image is used to assign each pixel to one of the land cover classes. A common method used by researchers is the feature extraction process to produce a supervised classification image which places all features into separate classes. This method classifies a digital photograph by recognizing spectral information from the image provided by the user, and then classifies the image based off the examples of the spectral signatures.

Landsat satellites have produced images that are used extensively for land analysis because of their synoptic view, multitemporal data archive, and large coverage. With multiple spectral bands within each scene, Landsat imagery has many research capabilities. The individual bands detect reflected or emitted electromagnetic radiation from visible to middle infrared, and to thermal spectrum of the Earth’s surface. Each individual spectral band is layered together forming a stacked image. Mapping urban expansion is an example how researchers have used feature extraction to classify land covers of different years to examine the changes. This usually occurs within large cities where population has increased resulting in an expansion of impervious lands. Feature extraction used to compare pervious against impervious lands is a
highly accurate application of this method. The spectral differences between pervious and impervious lands are high because the impervious lands are usually human made and have a similar reflectance value to other human made modified surfaces. Yuan (2008) researched the land use/land changes for the greater Mankato area in Minnesota from 1971-2003 using feature extraction. Land cover information was extracted from high resolution aerial photography, and then patterns and environmental factors were evaluated from the results (Yuan 2008). Four different features were classified, with cropland and grassland combined because their spectral signatures were very similar in the Black and White historical photos. Her research showed that large-scale vegetation mapping using feature extraction methods can be applied to analyze land cover types on landscapes such as the Tensleep Preserve.

1.4 Land Cover Types

Land cover is a fundamental variable which impacts on and links many different parts of the human and physical environments (Foody 2002). This thesis project is designed to highlight the changes of land cover in the Tensleep Preserve over a span of twenty-three years, and the specific focus is land cover not land use. Land use is the human aspect of design on land which could be industrial, residential, or commercial. The activity existing on the land will determine the land use type. However, this study does not evaluate the activity of humans at the Tensleep Preserve. The land cover type, which is mostly vegetation, is the focus. Mapping land cover change will specifically assist the Conservancy to protect endemic species and native vegetation on the property.

The use of a Global Positioning System (GPS) unit to collect truthing data for accuracy is a proven tool for land cover research, but most researchers in the past have collected field points only for the purpose of accuracy assessment. GPS can also be an exceptional tool for producing
an accuracy assessment of classified imagery. In this thesis I will use GPS collected data for feature extraction that will enable me to conduct land cover change analysis of my study area in the Big Horn Mountains. Feature Analyst, created by Visual Learning Systems (VLS), is an extension for ArcMap that enables users to extract features from a digital image. Feature Analyst is vital for my research because it allows the identification of specific vegetation types that otherwise would be difficult to classify using traditional per-pixel classifier such as maximum-likelihood. The inductive learner tool reads both the spectral and objects information from pixels in an image. The more information the pixels have, the better the software can distinguish differences from pixel to pixel. Many previous studies involving land cover change have grouped together land cover classes such as forests, croplands, and grasslands. My intent is to use Feature Analyst to classify vegetation by specific rangeland types that will help the Tensleep Preserve staff better understand change that has occurred over the past two decades.

1.5 Conservation Easements

Conservation easements are legal agreements with the landowners to restrict development rights on their lands with a tax incentive, cash payment, or both as an exchange (Fishburn 2009; Kiesecker 2007). Conservation easements have become the primary protection tool used by land trusts in the United States (U.S.) to achieve conservation goals and permanently restrict development and ecosystem fragmentation on private lands (Fishburn 2009; Kiesecker 2007). Monitoring easements in areas with high risk of residential subdivision is relevant to federal and state agencies that use public funds to pay for easements and seek the highest return on investments (Copeland 2013).

The Tensleep Preserve has an easement that borders Cook’s Vee and the management team needs to maintain it because the potential for residential development is high due to the
area’s beautiful scenery and its road and power line infrastructure. The Tensleep easement serves to regulate development and requires ecological monitoring of the land cover species along with invasive plant monitoring. Ecological monitoring can provide important information of the species and habitat persistence on conservation easements, but these data have been generally limited (Rissman 2006). At the Tensleep Preserve, invasive plant species like cheatgrass (*Bromus tectorum*) and houndstongue (*Cynoglossum officinale*) are aggressive and can form monoculture areas. This research can give the land manager insight on which areas of the easement may need restoration and/or protection measures to enhance native plant diversity. Also, findings can assist the land manager to locate areas that should be left alone because disturbances often increase the possibility of invasive plants encroachment. If properly enforced, the easement can protect the native vegetation and preserve the species which are also native to the region. Mapping land cover types at the Tensleep Preserve, including the easement area over a twenty-three year span, will provide quantitative information vital to its best management.

1.6 Definition of Rangeland

Rangelands are defined as land where the natural vegetation is predominantly grasses, grass-like plants, forbs, or shrubs, and where natural herbivory was an important influence in its pre-civilization state (Anderson et al. 1976). The type of rangeland found at the Tensleep Preserve is shrub and brush because Anderson et al (1976) classifies these areas having an arid and semiarid region with woody stems like sagebrush (*Aremisia tridentate*). The Tensleep Preserve contains arid areas with an abundance of sagebrush as well as humid creek valleys where an abundance of deciduous trees are located.
1.7  Sagebrush (*Artemisia tridentate*)

Sagebrush was once vast in the arid American west and covered most of the landscape. Wyoming contains large areas of contiguous sagebrush lands, and within the U.S. Intermountain region, the state is estimated to have 24% of all existing sagebrush (Connelly et al. 2004). Today there is an initiative to restore threatened sagebrush communities, so the analysis of this land cover is instrumental to the management of the Tensleep Preserve.

Semi-arid shrublands such as those consisting of sagebrush are difficult to distinguish in remote sensing environments, with discrimination made difficult by sparse and similar vegetation (Laliberte et al. 2007). Classifying sagebrush communities using remote sensing imaging is difficult because the topography and land cover from aerial photography looks similar and the difference between junipers and sagebrush is not easily detectable from on-screen visual analysis. Junipers and sagebrush communities have similar spectral information when analyzed in ArcGIS, even when high-resolution images are used for vegetation interpretation. This is the main reason why a GPS unit was used to collect ground truthing data at the Tensleep Preserve during the summer of 2013. Many areas on the preserve have shrublands where there is a mixture of juniper and sagebrush communities. The precise allocation of individual sagebrush and juniper communities will give the object-based classification method the spectral and spatial information necessary to separate the similar but different plant species.

Homer et al. (2012) analyzed the sagebrush communities in Wyoming using Landsat TM images and Trimble’s Definiens eCognition² software. As the most common semi-arid vegetation type in the state, sagebrush communities are threatened by fragmentation and degradation due to disturbances such as gas and oil development (Homer et al. 2012). eCognition is a similar software package to Feature Analyst in that it uses object-based
classification extraction which identifies objects to classify land cover from an aerial image. Homer et al. (2012) integrated three separate images at different scales for land cover analysis covering most of the state of Wyoming at elevations below 2377-m (Homer et al. 2012). They used 2.4-m QuickBird imagery, 30-m Landsat Thematic Mapper (TM) imagery, and 56-m Indian Remote Sensing Satellite Advanced Wide-Field Sensor (AWiFS) imagery with extensive ground sampling (Homer et al. 2012). The size of my study area is much smaller at 10088.37 acres (40.83 square kilometers) and therefore requires the highest resolution possible for the classification to produce acceptable results. Homer et al. (2012) produced a land cover map specifically highlighting sagebrush communities and measured statewide predictions of shrub cover across the state. This thesis uses a similar methodology, but the study area is smaller and my goal is specifically to classify all land cover types within the Tensleep Preserve.

1.8 Research Objectives

The objectives of this study are: (1) to create a classification image that maps the land cover types at the Tensleep Preserve using Overwatch Systems’ Feature Analyst; (2) to enhance the classification results and identify vegetation by using GPS truthing data on site of the study area; and (3) to quantify land cover changes using the post-classification method that will identify significant changes that the Tensleep Preserve manager can utilize for restoration projects and invasive weed removal. It is hypothesized that the classification images will have an acceptable accuracy assessment greater than 85% (Anderson et al. 1976) because the truthing data will provide excellent training data for the object classification and will be used as reference data for the accuracy assessment.

It is also hypothesized that the results from the post-classification analyses will reveal a change of sagebrush communities to juniper pines or grasslands from 1989 to 2012. Sagebrush
(Artemisia spp.) has essentially no value to ranchers; therefore, the removal by either prescribed burn or mechanical means has been a common trend. This removal occurs in the surrounding areas but not on the preserve directly. Within the Tensleep boundary, other factors contribute to sagebrush loss such as invasive species and climate change. The sagebrush is home to the greater sage-grouse (Centrocercus urophasianus), a keystone species which is in crisis because the sagebrush community has greatly reduced in the west. This study can help with future sagebrush restoration projects which could be funded by the Greater Sage-Grouse Initiative. The Tensleep Preserve welcomes science based stewardship when the protection of land and waters is a priority, so this land cover analysis will be beneficial specifically for the land manager at the Tensleep Preserve. Furthermore, this research can be used by the TNC Wyoming Chapter for resource management and conservation modelling projects to restore or protect sensitive areas.
2. Literature Review

This study is concerned with the accurate extraction of land cover data and vegetation classes from high-resolution aerial imagery and other data sources using Feature Analyst. This literature review will examine the existing literature relevant to the techniques used in this research study. I will first discuss the importance of land cover analysis and then give an overview of the relevant research on land cover change, object-based classification and the importance of protecting natural lands.

2.1 Land Cover and Land Cover Changes

Land cover change analysis using remote sensing imagery and GIS processes have been utilized for decades but have greatly improved in recent years. Analyzing aerial photography using computer software like ArcGIS and ERDAS Imagine has allowed for detailed spatial analysis. Digital change detection is the process of determining and describing changes in land cover properties that are based on remote sensing data (Shalaby and Tateishi 2007). The Tensleep Preserve is a protected area so land use is a term not relevant in this research because the purpose of the Tensleep Preserve management is to prevent development and protect the endemic species present. The goal of this research is to detect land cover changes over time and provide images for examination and spatial statistics of the changes. To accomplish this purpose there are different land cover change techniques which highlight the changes that have occurred in an area by distinguishing image differences. In the past ten years, machine learning algorithms have emerged as a more accurate and efficient alternative to conventional classification methods for mapping land cover (Radriguez-Galiano et al. 2012). An important aspect of land cover analysis is the availability and resolution quality of aerial imagery. Historical aerial photography and satellite imagery that are available for land cover analysis date
back to the 1930s and 1972 respectively on the United States Geological Survey (USGS) aerial photographs and satellite images website (http://www.usgs.gov/pubprod/aerial.html). These images are available to the public in digital format. Land cover change analysis uses many different types of images including Landsat MSS and TM+, MODIS, NHAP, NAPP, and NAIP. Both aerial photography and satellite imagery have been used successfully for land cover analysis. This research will use NAIP and NAPP aerial photographs and a scene from the Landsat TM series for land cover analysis. The NAIP aerial photograph was chosen because the resolution is high at 1-m and represents the latest aerial photograph compared to the collected GPS truthing data. The Landsat 5 TM scene and black and white NAPP aerial photograph were chosen because the NAPP had the best resolution to represent the closest date when the property was purchased. The Landsat 5 TM scene was used to add additional spectral information to the NAPP aerial photograph.

An accuracy assessment is an importance measurement, especially for land change analysis, to give an assurance that the classification threshold of the thematic classified map is acceptable. This measurement can be derived from a confusion matrix with the producer and user accuracy in rows and columns comparing correctly allocated number of cases to the total number of cases of that class (Foody 2002). The acceptable overall accuracy for dependable analysis when extracting features from imagery was originally determined by Anderson et al. (1976) at 85 percent for level 1 classification map. Yuan (2008) integrated remote sensing and GIS with utilization of Feature Analyst. The integration of remote sensing and GIS can provide accurate and detailed land cover and land use information with remote sensing images from the past and present.
A quantifiable method to measure land change is post-classification comparison. Post-classification comparison detects the simple changes of derived thematic maps attempts to quantify the different types of change (Shalaby and Tateishi 2007). This type of comparison is valuable because the area of land cover can be large, so making field monitoring time consuming and difficult depending on the topography. The primary concern of classifying different vegetation types is the correct identification of spectral differences between the vegetation species. Most vegetation types such as forest cover, grasslands and even agriculture are difficult to separate into separate classifications because their spectral signatures are often similar. Research evaluating urban growth usually has no need to separate these classes, and combining them would suffice for most project needs. However, this research attempts to separate the different but spectrally similar vegetation types that are present at the Tensleep Preserve using Feature Analyst techniques.

Vegetation analysis can be difficult when combining GIS and remote sensing because mixed pixels can reduce the accuracy of a classified image. To resolve the mixed pixel issue, satellite imagery with high resolution has greatly improved reducing the probability of pixels containing two or more different classes. The greater resolution simply reduces the cover area per pixel, thereby decreasing the possibility of two or more classes lying within a single pixel. Furthermore, the collection of spatial truthing data with a Trimble GPS unit will give examples of different vegetation types on the preserve. The purpose is to identify the spectral signatures of individual plant species on the preserve and create different land cover types based on the collected GPS data (Goodchild 1994).
2.2 Feature Analyst

Feature Analyst (FA) is specialized feature extraction software extension of ESRI’s ArcGIS that analyzes both spectral and spatial/contextual properties of the pixels of a raster image. Other similar software for feature extraction were considered for this thesis project, but I selected FA to execute the object-based land cover classification for this project because the software was easy to learn and user friendly. The FA Learner depends upon several information inputs that determines whether or not image pixels are represented in the target feature which is identified in the training set (Yuan 2008). The Learner software reads both the pixel values and spatial information. It identifies objects when classifying an image.

In 2001 Overwatch Systems (formerly Visual Learning Systems, Inc.) developed FA as a commercial-off-the-shelf automated feature extraction extension for ArcGIS in response to the geospatial market’s need for automating the production of geospatial features from earth imagery (Blundell and Opitz 2008). Originally funded by NASA and the Department of Defense, FA uses a machine-learning algorithm to achieve automated feature extraction (Riggan and Weih 2009). As an add-in extension for ArcGIS, the software identifies and learns from the user-specified examples to identify classifications. Feature Analyst provides users with a powerful toolset for extracting object-specific, geographic features from high-resolution pan-extracting and multi-spectral imagery (Opitz and Blundell 2008). The software automatically develops a model that correlates known data (spectral or spatial signatures) with targeted objects of interest and the learned model automatically classifies and extracts the remaining targets or objects (Blundell and Opitz 2006). The object-based classifier not only takes into account spectral and spatial factors, but also includes the object’s shape, texture, pattern, and spatial context in relationship with neighboring objects (Nagel et al. 2014). FA uses the inductive learning based
approach to object-recognition and feature extraction, and was designed for both a workflow and user interface perspective to provide a familiar collection environment for the user (Blundell and Opitz 2006). This program also uses a combination of texture, reflectance, and spatial context information to classify land cover from high-resolution imagery (Davies et al. 2010). The software is similar to other standard supervised classification systems where the user supplies training sites of each feature of interest (Vanderzanden 2002).

Land cover changes can be difficult to map when the spectral variance between features is small. For example plant species can be difficult to differentiate because the spectral difference between the species is minor making the separation challenging. Research studies that have evaluated land cover change were usually those examining urban expansions upon forests and rural areas. It is important to understand the space we live in and the extent of human sprawl to better protect vital natural resources that life depends upon. Natural areas that have rich biodiversity are important to protect and these areas can also serve as research indicators for studies about the changing landscape. Land cover change analysis can give insight to trends that have occurred in an area and shows what is changing and the extent of the change.

Feature extraction software has improved over the last decade leading to more accurate land cover analysis from high resolution images. Similar software has been successful for land cover change analysis but FA has unique built in tools that allow the user to create training data and select from different classification settings to enhance results.

2.3 Object-based Image Analysis

Pixel-based classification systems make the attempt to identify the class of each pixel in the imagery by comparing the \( n \)-dimensional data vector for each pixel with the prototype vector for each class (Shackelford and Davis 2003). The mixed pixel results are an issue with pixel-
based classification. This occurs when more than one class is within a single pixel and the result is a pixel misclassified within an individual pixel. This results in inaccurate classification images and the resulting land cover change analysis is not accurate. Each pixel from an image is classified separately into a predetermined class depending on that pixels spatial and spectral values. The traditional per-pixel classification of remotely sensed images is limited by mixed pixels (Cracknell 1998). Pixel-based land cover classification methods, such as maximum likelihood classification, use the spectral information contained in individual pixels to generate land cover classes. The maximum likelihood classification has recently been challenged because texture and topological relationships are not included in pixel-based classifications (Aguirre-Gutiérrez et al. 2012).

An object-based classification is a relatively new concept compared to traditional pixel-based classification methods used in remote sensing. The issue with pixel-based classification is that each pixel is identified separately without the consideration of the surrounding pixels. Fundamentally, the consideration of near pixels is extremely important when classifying land cover because when computing the classification groups of pixels are important. The First Law of Geography defined by Waldo Tobler (1970) is that “Everything is related to everything else, but near things are more related than distant things.” Land cover, especially vegetative regions, can benefit from object-based classification methods because variations in surrounding pixels as well as non-spectral information are also measured. This is important for producing land cover classification images of areas with vegetation because the pixels are likely to be spectrally similar. Ordinary pixel-based classification would not be able to compute the similarities of the Tensleep Preserve vegetation because there are too many similar pixels and would likely result with an image with salt and pepper results. An object-based classification could identify the
patterns of vegetation groupings on the preserve which would better distinguish the spectral differences between the neighboring vegetative species.

Object-based methods have been used since the 1970s, and recently image segmentation has been the most commonly used approach for image analysis. Segments are regions which are generated by one or more criteria of homogeneity in one or more dimensions respectively (Blaschke 2010). These segments are derived from a set of many alike pixels and contain more information than a single pixel. Generally, object-based classification works in the same way as a pixel-based classification, with the difference being that each pixel is not classified separately, instead all pixels from each object are classified together (Walter 2004). Pixel-based image classifications detect the value of each individual pixel, so results may vary depending upon image quality and resolution. Pixel based classification of high-resolution images has several drawbacks, such as low classification accuracy, very limited spatial information to be derived and salt-and-pepper effects (Chen 2012). On the other hand, object-based classification methods initially segment the original remote sensing image into objects instead of the single pixels used in the classification process (Nagel et al. 2014). Furthermore, object-based image analysis is different from the traditional pixel-based classification methods in that object-based techniques group similar and neighboring pixels into distinct image object within the designated parameters (Riggan and Weih 2009).

A classic example of how per-pixel classifications can become problematic occurs when rooftops and roads are compared while attempting to identify each separately from an aerial image (Myint et al. 2011). Classifying such features is difficult because their spectral signatures are similar, so the extraction of each and the separation into separate classes can become problematic.
2.5 Feature Analyst Related Research

2.5.1 Impervious and Pervious Surfaces

Yuan’s (2008) successful use of Feature Analyst can serve as a model for land cover mapping in the Tensleep Preserve. She analyzed the decline of pervious surfaces in the greater Mankato area from 1971-2003 using the hierarchical machine-learning FA classifier. The accuracies of the classifications for each year (1971 and 2012) were above 92% while the Kappa statistics are 0.87 and 0.90 respectively. The representation of rural classification was a mix of different vegetation land cover types in her study area. For example agriculture, forests, and wetlands were grouped together as one class. This grouping of land cover types was practicable for her research because it was unnecessary to separate these different vegetation types for analysis. The research objective for this project is to use FA to separate the different but similar land cover types at the Tensleep Preserve. Therefore the separation of different vegetation types is the focus and the results will determine if the object-based classification can successfully identify and separate spectrally similar land cover types.

Similar to Yuan’s (2008) research which separated impervious and pervious surfaces, Miller, Nelson and Hess (2009) also used FA to classify aerial images to detect impervious and pervious land cover types. Miller et al. (2009) used BullsEye 2’7 input representation (Figure 2.1) for their FA extraction of 2003 digital orthoimagery with a spatial resolution on 33cm which was acquired from the United States Geological Survey (USGS). Their study area was located in Wake County, North Carolina where they created two sets of training classes representing impervious surfaces such as buildings, and parking lots, while bare soil, forest floor, and lawn represented pervious surfaces. The accuracy assessment followed Congalton’s (1991) recommendations with a total overall accuracy of 85 percent. The FA overall accuracy was 91.7
percent for the 111 nonmosaicked, very-high-resolution images using an iterative training technique. The goal of the study was to produce a rapid accurate classification of the impervious and pervious surface cover from high-resolution imagery. The study concluded that the FA software was an effective in extraction. Incorporating advanced GIS and remote sensing applications might further improve the capability of object classification.

Figure 2.1. Bull’s eye 2’7 representation used by Miller et al. (2009) for classification.

2.5.2 Land Cover Classification

Another research example that used FA to classify vegetation types is Madsen et al. (2011) that mainly focused on the identification of two species. They researched the expansion of pinon and juniper trees into the shrub-steppe communities in Utah’s Division of Wildlife Resources Range Trend Project (DWR-RTP). Madsen et al. (2011) found that the FA software provided an adequate method for extracting pinion and juniper trees for assessing the encroachment extent of those species. The objectives of this study were to develop an efficient and effective method for accurately quantifying pinion and juniper cover from high resolution photographs and compare feature-extracted data to typical in-situ datasets used by land managers. Tree cover was extracted from the aerial photographs collected using Feature Analyst. Pre-defined foveal pattern of nine cells was the most accurate search pattern for pinion and juniper canopy cover extraction. Madsen et al. (2011) completed an on-screen accuracy
assessment of cover for each site using ERDAS Imagine 9.1 and thirty-five randomly generated points were used. Training sites were digitized using FA from the 25-cm spatial resolution aerial photograph. The training sites were represented by either tree or non-tree. The on-screen overall accuracy for the pinon and juniper feature extraction was 95 percent with a Kappa statistic of 0.90.

Mirik and Ansley (2012) researched the woody plant encroachment into grasslands and rangelands measured by 1-m resolution NAIP and 30-m Landsat TM images. The study area was an 800 km² area in northern Texas and the rangeland consisted of mainly mesquite/grasses in the southern part of Wilbarger County. A classification was performed using FA with four different land cover types used. The study objectives were to compare the classification values of two different images with different spatial resolutions (1-m and 30-m); and to compare the two image types for detecting different percent covers on small patches. The four land cover types to be classified are mesquite cover, grass cover, bare ground, and other which comprised of all other land cover types including roads, water bodies, and residential areas. The training data used for FA was manually digitized using 50 polygons for each land cover type at identified locations on the images and on the ground. The accuracy assessment from the NAIP image yielded a higher overall accuracy compared to the Landsat TM image, an expected result considering the resolution differences between the two images. The NAIP image had an overall accuracy of 94 percent with a Kappa value of 0.89 while the Landsat TM image overall accuracy was 87 percent with a Kappa value of 0.77. Also, an error matrix was generated from the referenced and classified data for both the 1-m and 30-m images displaying the mesquite, grass, bare ground, and other land cover classes (Mirik and Ansley 2012).
Their results from the land cover classification using FA were mostly satisfactory with the exceptions of the bare ground from the 1-m image and the “other” class from the 30-m image classification. This was a direct result from the image having mixed classes within a pixel or pixels. Therefore, the Landsat TM 30-m image classification results grossly overestimated the mesquite cover and was determined to be inadequate for detection of this native invasive woody species. This study initiated the use of an NAIP image for the purpose of land cover classification at a large scale. With the accuracy levels for each classified images at a respectable and acceptable percentages, this study proved useful for classifying vegetation using FA as a reliable object-based classification extraction tool. The authors also recognized that further research is needed to determine whether the methods used could be applied to other ecosystems and different NAIP and Landsat images (Mirik and Ansley 2012). My research in this thesis recognizes the resolution issues caused by the Landsat TM image and measures were taken to correct the inconsistencies. The measures that were applied to resolve the possible inconsistencies with a low resolution image like the 30-m image will be addressed in the Data Processing section.

As a service for the national forests, the United States Department of Agriculture (USDA) Forest Service Remote Sensing Application Center (RSAC) evaluates software that could be beneficial to forest resource management. Vanderzanden and Morrison (2002) used medium resolution images and FA to extract forest information from a QuickBird2 1-m image using bands 2, 3 and 4. The 2.4-m multispectral bands and 0.6-m panchromatic data were resampled to produce the one meter QuickBird2 image. Four land cover classes were used for extraction from an area in the Tongass National Forest in Alaska. The classes that were extracted were non-forest, conifer, hardwood, and mixed forest. The Quickbird2 extraction
results were compared to Landsat TM and Landsat TM texture layer (Vanderzanden and Morrison 2002).

The accuracy assessment included 30 randomly selected locations from each classification scheme. Of the three different images, FA overall accuracy for size and structure was 80.0 percent, while the TM texture image was 87.1 percent, and the TM unsupervised classification was 71.9 percent. Their findings showed that FA was able to separate the land cover types with high accuracy using high resolution imagery and with working knowledge of ArcGIS (Vanderzanden and Morrison 2002).

Hamada et al. (2011) examined sagebrush communities which are home for many endangered and threatened species and hold a high degree of biodiversity. The objective of this study was to test the effectiveness of remote sensing approaches, consisting of combinations of four types of multispectral imagery and three image analysis models, for estimating fractional cover of four cover types within California sage scrub communities of southern California. Different input imagery and processing methods were used to accomplish these objectives. FA was used for the artificial neural network classifier (ANN) where the model first developed three cover types. Overall, this processing methods consistently yielded higher accuracy across cover types. When considering data availability and cost effectiveness, object-based image analysis proved an effective method for mapping cover of true shrub, subshrub, herb, and bare ground. They concluded that using a pansharpened QuickBird multispectral imagery with 0.6-m spatial resolution yielded the best results for extracting California sage scrub.

Davies et al. (2010) aimed to investigate the ability of feature-extraction software to estimate western juniper cover from color aerial photographs obtained from the National Agriculture Imagery Program (NAIP) and explore the relationships between juniper cover at
stand closure and environmental/site indices and characteristics measured from commonly available geospatial data layers. The study area covered 12,340 hectares located on Juniper Mountain in Idaho with natural vegetation currently consisting of sagebrush-grasslands and western juniper woodlands (Davies et al. 2010). The training data for Feature Analyst classifier was set to represent either juniper cover or non-juniper cover with the seven-cell bull’s-eye search pattern for extracting juniper cover (Davies et al. 2010). The overall accuracy of the NAIP juniper extraction was 92%, however there were only two classes extracted, juniper and non-juniper. These results are advantageous because western juniper control programs are often constrained by finite resources and thus, being able to estimate juniper cover over large landscapes accurately will make these projects more affordable. Accurate estimates of western juniper cover are essential to prioritizing management and selecting the appropriate treatments in juniper control programs to restore sagebrush steppe plant communities (Miller et al. 2005).

Estimating western juniper cover across large areas with NAIP imagery is an efficient and effective technique for landscape restoration projects. Thus, some of the constraints in implementing landscape-scale restoration projects can be alleviated by using aerial images. These images can also be used to prioritize management by level of juniper cover. The work of Miller et al. (2005) demonstrated that using remotely sensed imagery to determine juniper cover and environmental/site variables can be an effective tool to direct landscape-scale restoration projects that would otherwise be prohibitively expensive to implement. The results suggest that NAIP imagery and environmental/site characteristics measured from commonly available geospatial data layers have the potential to be useful in landscape-scale restoration projects and land management in the Intermountain West and other ecosystems (Miller et al. 2005).
The estimation of western juniper cover in the western United States developed by Miller et al. (2005) used the seven cell bull’s-eye search pattern with a minimum aggregate of four pixels, proven to be an effective method for extracting juniper cover. After classification, the results were examined visually and juniper sites that were either overestimated or underestimated were reclassified using the Feature Analyst hierarchical learning tools (i.e. clutter removal, and missed features). To determine the accuracy of the NAIP imagery of juniper cover or non-juniper cover, seventy-five random points were generated and assessed. Detecting only juniper species was difficult because other similar vegetation types have reflectance that relate to junipers, particularly in areas that have western juniper and other vegetation species highly intermingled. Estimating juniper cover from NAIP imagery and potential juniper cover from commonly available geospatial data layers to direct management makes landscape-scale restoration projects more feasible (Miller et al. 2005). Combining the information acquired from remotely measured juniper cover and environmental/site variables has potential to be especially useful in direction management.

Riggan and Weih (2009) studied the land use and land cover (LULC) in and around Hot Springs, Arkansas comparing pixel-based and object-based classification methods. LULC methods in the past have been produced using pixel-based classifications which has limitations due to low resolution. The availability of higher resolution images in recent years necessitated the improvement for land cover and land use extraction methods. GIS specialists have recently compared the traditional pixel-based classifications to the newly developed object-based classification procedures for classifying land cover. The purpose of this project is to compare these methodologies and determine if an object-based analysis of merged medium-resolution, multi-temporal satellite imagery and high-resolution digital aerial imagery will produce a LULC
map that is more accurate than a supervised pixel-based analysis. The Hot Springs National Park in Arkansas is the study site and the area is approximately 16,850 hectares with a combination of rural, forest, urban areas. The input representation for the FA supervised classification used the Manhattan shape with a 13 pixel-width which provided a window with a total of 85 cells per band. Field data, or ground-truthing, was conducted on the study area in order to create a “test set” to be used in the accuracy assessment of the two classification images. Training sets were developed and an accuracy assessment was performed for each classification to determine which LULC procedure was the most accurate. The accuracy assessment was accomplished using the error matrix method which measured the producer’s and user’s accuracy and the overall accuracy for each cover type (Riggan and Weih 2009).

The overall accuracy of the pixel-based classification is 66.9 percent while the object-based classification was 83.0 percent. Both classification methods were able to distinguish the mixed forest class accurately which was not surprising since the class had a combination of conifer and deciduous forest classes. This study demonstrates that the FA software can produce an accurate land cover/land use classification when applied to medium-spatial, multi-spectral satellite imagery merged with high-spatial resolution aerial imagery. The object-based classification was considerably more accurate when compared to the pixel-based (supervised) classification which was expected because the high quality imagery used (Riggan and Weih 2009).

2.6 Post-classification Change Detection

Detection of land cover types from aerial imagery between different years is a useful tool for land management and an effective way to analyze land cover change. Post-classification comparisons of resulting classification maps go beyond simple change detection and attempt to
quantify the different types of change (Shalaby and Tateishi 2007). Shalaby and Tateishi (2007) comprised a post-classification image to detect the land cover change in Egypt to quantify the changes of land degradation and desertification caused by urban sprawl and agriculture lands. They acquired Landsat images from 1987 and 2001 to produce supervised classification maps with seven different land cover types for change detection. The cross-tabulation explained some important land changes including the change of grassland to cropland as a positive change not degraded lands. This is a great example why the integration of remote sensing and GIS in the studies of land cover change detection because it provides information about the nature and spatial distribution of land cover changes (Shalaby and Tateishi 2007). Furthermore, using cross-tabulation comparison Shalaby and Tateishi (2007) were able to detect land degradation causes such as irrigations schemes, wind erosion and overgrazing.

Change detection is the process of recognizing differences in the state of an object or phenomenon by observing it at different times (Lavigne et al. 2006). Change detection using airborne and space borne produced aerial imagery has constantly improved over the past few decades. However, the post-classification comparison which is a land cover analysis technique used in object-based change detection can be difficult. Classifying features of interest correctly can be difficult especially when low spatial resolution imagery is used. Lavigne et al. (2006) compared three types of automated feature extraction tools to extract geospatial features. Their research revealed that FA extracted features with higher accuracy than the other automated feature extraction tools. FA also yielded higher overall accuracies for change detection of the manmade features.

Singh’s (1989) review article stated that the post-classification comparison technique was the most obvious method of change detection that required the comparison of independently
produced classified images for analysis. This technique is a pixel by pixel comparison of two images at different times and holds promise because data from the two dates are separately classified. This minimizes the issue of normalizing for atmospheric and sensor differences between the two dates. A common issue with this technique is the number of erroneous change indications if either date gives a false indication of change, therefore a joint classification of two images having 80 percent accuracy will produce a 64 percent post-classification comparison image. Despite this erroneous indicator, this form of image differencing is the most widely used technique for change detection and can be used in a wide variety of different environments (Singh 1989).
3. Methods

3.1 Data Acquisition and Preprocessing

The data used in this study were obtained from the USGS EarthExplorer (http://earthexplorer.usgs.gov/), the Geospatial Data Gateway (https://gdg.sc.egov.usda.gov/) and The Nature Conservancy, Wyoming Chapter. The specific datasets were 1989 mid-resolution (3.52-m) digital ortho-imagery, 1989 Landsat 5 TM (30-m) imagery, 2012 high-resolution digital ortho-imagery (1-m) and boundary data.

3.2 Aerial Imagery

The 1989 image consists of nine layers which were fused from two separate images. This aerial imagery was part of the National Aerial Photography Program (NAPP) which was operational from 1987 to 2007, and coordinated by the USGS as an interagency project to acquire cloud free black and white and color infrared aerial photographs at an altitude of 20,000 feet above mean terrain elevation. (USGS NAPP). The goal for this research was to acquire imagery from 1980 because that is when The Nature Conservancy purchased the property, the quality of those images were not acceptable for this project. The best quality imagery found near to the acquisition date and usable was the NAPP series. NAPP was derived from black-and-white panchromatic film sensitive to the electromagnetic spectrum and is in continuous tones of grey ranging from black to white (USGS NAPP). The image has a 3.52 meter per pixel resolution, with a radiometric 16 bit pixel depth. A total of five images from the NAPP collection dataset were downloaded then mosaicked to cover the entire Tensleep Preserve boundary study area.
The second 1989 remote sensing imagery used was part of the Landsat 5 TM satellite collection. The Department of the Interior, NASA, and the Department of Agriculture developed this Landsat series missions which began acquiring images on July 1972. The Landsat 5 TM satellite had a 16-day cycle beginning March 1984 and was decommissioned January 2013. The original image data file used in this research consisted of seven spectral bands, but this project used bands 1-5 and 7 at 30 meter per pixel with a radiometric 8 bit pixel depth. Band 6, an infrared which was collected at 120 meters per pixel was not used in this research.

The 2012 aerial imagery was part of the NAIP funded by the U.S. Farm Services Agency (FSA). The 2012 NAIP ortho-image was collected in July during the peak agriculture growing season, and is considered a ‘leaf-on’ representation of peak growth.

All five images were downloaded from the USDA Geospatial Data Gateway and the USGS internet pages free of charge. Likewise, the NAIP images were acquired from the Geospatial Data Gateway webpage. The NAPP and Landsat 5 TM images were downloaded from the USGS EarthExplorer webpage. The Landsat TM image was converted from digital number to reflectance using ERDAS Imagine 2015. The haze and clouds were minimal on the Landsat 5 TM image, so there was no need for processing. The conversion gives reflectance values from the image which is important for true analysis especially when classifying a rangeland area for land cover analysis. The NAPP image was created by mosaicking five contiguous NAPP images using ERDAS Imagine to ensure the entire study area was included. Then, the boundary of the Tensleep Preserve was masked and georectified. After the Landsat TM and NAPP images were masked, they were fused together so the output image contains both spectral and feature information along with all layers from both. The purpose for this process was to provide as much information within the image of the area of interest for FA to
differentiate the vegetation species into separate class categories. It can be very difficult to
differentiate grassland and cropland in black and white imagery because of the low spectral
variation and complex topography (Yuan 2008). Therefore, Yuan (2008) defined both grassland
and cropland as a single mixture class when extracting the land covers and used a fused image
with an added a texture layer which provided additional image information with the purpose of
reducing classification accuracy error. A main goal of this research was to improve the variation
between the different vegetation types which in turn would yield more accurate land cover
change analysis.

Many researchers used FA for land cover extraction from easily identifiable features such
as buildings and roads versus forests and other vegetation, but this research aims to test FA’s
ability to identify very similar rangeland cover features on the Tensleep Preserve with the use of
collected GPS truthing data to guide the training data.

3.3 Global Positioning System (GPS) Data Collection

The data collection with the Trimble Juno unit was conducted from June 11 through June
29, 2013. The collected data was saved on the GPS unit therefore the collected polygons were
visually viewed and verified. The typical collection method was determining a location to
allocate a specific vegetation by a hike for a few hours either walking to an area of interest or
seeking out areas larger than 1-meter square. The aerial images that were used from recent years
have a resolution of one meter therefore each pixel in those images are one meter square.
However, it was known that larger patches would benefit the feature extraction process.
Therefore the vegetation that was collected were the areas known to have one species in close
vicinity and the largest patches. If a patch of vegetation or a single plant species was only one
square meter or less, that area was ignored to prevent mixed pixel issues during the land cover
type classification process. The main focus of this research and collection was focused on vegetation, but other features like dirt road, rock and bare land were also collected. Vegetation patches were the main focus during collection and that is the emphasis here in this chapter.

When the desired patch of vegetation was located, I selected the species type from the data dictionary options from the GPS unit. Starting at an area on the perimeter of the patch, I started the GPS collection while walking around the entire patch only including the plant species selected. Avoiding the collection of vegetation species which had similar species nearby was a collection goal so the classification process was precise and clear.

Ground truthing data was collected from June 11-29, 2013 using a Trimble Juno GPS unit. A data dictionary was created in the field using a Trimble Juno GPS unit from Minnesota State University, Mankato student Dustin Marlow. He was visiting Tensleep Preserve with the Field Ecology class and fortunately had an older software version on the GPS unit he brought along. The newest version for the Trimble Juno unit, which I uploaded before my data collection, oddly did not allow in the field data dictionary creation. Therefore, a data dictionary was created using his GPS unit then transferred via SIM card to my GPS unit. The data dictionary collection included the different plant species present on the preserve which represents the dominant communities. The data dictionary proved valuable, forms of polylines for data collection of the different vegetation species types and reduced the collection time. The data dictionary provided the ability to locate vegetation and collect polylines with ease without the need to create new polyline features for each collectable feature.

Different vegetation species types were identified and collected only if the plant community was larger than 1-m square. The data collection goal was to identify the dominate plant communities on the preserve that represent a large area in different locations. The variety
of the different vegetative communities were then used as representatives for the training data in FA. The accuracy of the truthing data is important so the correct plant communities are identified in the exact location represented on each image. The collected truthing data were corrected using the differential correction in Pathfinder Office and the USGS base station used was from Tensleep, Wyoming. Correcting the data assured that the collected truthing data would be represented correctly on each image for proper vegetation identification. The corrected data were then viewed in ArcMap to verify that the vegetation identification correctly matched vegetation on the image. Because I spent the 2011 summer season on the Tensleep Preserve, I was able to learn the different vegetative types on the preserve and where large patches are located. This personal experiences enabled me to correctly identify the vegetation classes when extracting the different vegetation species from the imagery. For instance, this research ground truthing collection process mainly took place from Cook’s Vee (Figure 1.1) which is dominated by grasslands, sagebrush, bare land and juniper pines. Cook’s Vee is the area between Cook’s Canyon and Canyon Creek. Locating these patches of vegetation with ease reduced the collection time and assured that the collected data was identified properly.

The Tensleep boundary shapefile was acquired from The Nature Conservancy Wyoming Chapter in 2011. The shapefile is a combination of the easement and property boundaries which are both operated by the Tensleep Preserve manager. The shapefile included the easement as an additional polygon attached to the Tensleep Preserve boundary. This easement came with the property when The Nature Conservancy purchased the land from the National Girl Scouts West. The Tensleep shapefile was used for masking to provide images that only showed the property features. All images were set to the projection coordinating system UTM NAD 83 zone 13.
3.4 GPS Differential Correction

All collected GPS data was corrected using the Tensleep base station and GPS Pathfinder Office program. A total of three Trimble field data files were downloaded and corrected using the Ten Sleep CORS (Continuously Operating Reference Station) base station as the differential correction base station location. The data correction is important because it improves the truthing data and will assure that the collected GPS truthing data will provide quality control when mapping land cover at the Tensleep Preserve. After the files were corrected each file was then displayed using ArcMap to confirm the corrected data was accurate by comparing the uncorrected data with the new corrected data. Furthermore, the corrected data was also compared to the NAIP 2012 image to assure the data aligned with the corresponding land cover type.

3.5 Data Preparation/Aerial Imagery

The July 4, 1989 Landsat 5 TM image was downloaded and the (bands 1-5 and 7) layers were stacked using ERDAS Imagine 2014. This image was then masked to the Tensleep Preserve boundary and radiometric corrected to show reflectance of the earth’s surface for true ground results. The result from the radiometric correction process gives each pixel a digital reflectance value which represents the reflectivity of land features.

The final NAPP/Landsat stacked image contains nine layers with the first three represent the blue, green, and red (true color layers) from the NAPP image. The other six layers are bands 1-5 and 7 from the Landsat scene. The inclusion of Landsat band 4 is important since this near-infrared layer detects vegetation well. The panchromatic layer was excluded because the black and white reflectance does not adequately differentiate land cover species.
The NAIP 2012 was masked to the Tensleep boundary shapefile and consisted of three layers which are the blue, green and red (visible spectra) from the original aerial photograph. No additional layers were added to this image because the 1-m resolution has enough detail within each pixel for the extraction process to produce a satisfactory classification outcome.

3.6 Land Cover Classification

The land cover classification of the 1989 image and the 2012 image was completed using the ArcGIS extension Feature Analyst which uses an inductive learning classification algorithm. The class scheme was determined before the classification extraction process by utilizing the GPS collected truthing data for setting up the training data for the extraction and separation of the different land cover type classes. A total of ten land cover classes were extracted: agriculture, grassland, juniper pine, sagebrush, ponderosa pine, limber pine, dirt road, bare land, rock and creek deciduous mix. These specific vegetation classes were chosen because they are the dominant plant species present on the preserve. The non-vegetative classes were collected to represent non-vegetation land cover at the preserve. The correct/incorrect function of FA was not used because the classification results did not improve the accuracy of the classified image. This may be a result of the land cover classes having similar spectral signatures.

3.6.1 Land Cover Classes

Ten different land cover classes were used for collection and the production of a supervised classification image for two years. The ten land cover classes were determined from experience on the preserve for the summer of 2011, discussions with the land manager, and quantifiable collectable GPS data. There are obviously much more different land cover types on the preserve than the ten classes used in this research, such as limber pine and aspens. The ten classes of land cover types were chosen based on the availability to collect ground truthing data
and the types which could be analyzed using an aerial photograph. Also, the supervised classification process would only be able to quantify areas that covered a meter square because the images used for processing will not have a resolution coarser than 1-m. In fact, the 1989 image has a resolution of 3.71-m, therefore any land cover smaller than a single pixel will be difficult to classify properly.

![Image of land cover types](image.png)

Figure 3.1. Pictures of the ten land cover types chosen for analysis at the Tensleep Preserve.
Table 3.1. Land cover classes used for the Tensleep Preserve truthing data GPS collection.

<table>
<thead>
<tr>
<th>Land Cover Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>Irrigated land used for cultivating hay</td>
</tr>
<tr>
<td>Juniper Pine</td>
<td>Coniferous woodland standing 10-15m</td>
</tr>
<tr>
<td>Lodgepole Pine</td>
<td>Tall slender and straight conifer</td>
</tr>
<tr>
<td>Ponderosa Pine</td>
<td>Tall conifer with red bark and branches near the top</td>
</tr>
<tr>
<td>Rock</td>
<td>Rock formations include cliffs, boulders, large areas with boulder cover and no vegetation</td>
</tr>
<tr>
<td>Bare Land</td>
<td>Absence of vegetation and is not rock or dirt road. Areas with small stones or dirt like formations</td>
</tr>
<tr>
<td>Sagebrush</td>
<td>Perennial shrub standing 2-5m with silvery leaves</td>
</tr>
<tr>
<td>Dirt Road</td>
<td>Manmade gravel paths used for vehicle travel</td>
</tr>
<tr>
<td>Grassland</td>
<td>Areas covered by a variety of grasses</td>
</tr>
<tr>
<td>Creek Deciduous</td>
<td>Leafy plants near creeks. i.e. Aspens and other leafy plants</td>
</tr>
</tbody>
</table>

3.7 Post Classification Comparison

ERDAS Imagine 2015 was used for post processing change analysis of the two different image years. Digital change detection is the process of determining and describing changes in land cover properties based on multi-temporal remote sensing data (Shalaby and Tateishi 2007). The 1989 stacked NAPP/Landsat TM nine-layer image served as the “before image” while the 2012 NAIP three-layer image was the “after image”. The analysis was completed by comparing the per pixel values from the 1989 and 2012 supervised classified images using the matrix union feature in ERDAS Imagine 2015 which is a two layer union operation in the thematic tools. The process takes the classes from the input raster files and determines how the classes overlap. The output layer file represented the land cover change from the 1989 supervised classification image.
as compared to the 2012 supervised classification image. The acres from each land cover class change were calculated using ERDAS Imagine 2015. Remote sensing and GIS provide opportunities for integrated analysis of spatial data in particular when cross-tabulation which compares the categories of one image with those from a second image and the tabulation of the number of cells in each combination (Shalaby and Tateishi 2007). This research will have a total of 100 different land cover changes from the post-classification comparison image because the ten different land covers are compared against each other. These comparison results from the post-classification analysis will highlight the area that have had no change to the areas that have had the most change of land cover at the preserve.

3.8 Accuracy Assessment

An accuracy assessment was conducted on each of the 1989 and 2012 supervised classification images. Due to the small size of the Tensleep Preserve, 10,088.3 acres (40.80 square kilometers), a set of 200 random points was created. Congalton (1991) suggests that the number of samples for each category should be adjusted based on the importance of the class for the objectives of the map. The set of 200 random points was selected and is sufficient for this study because the generation of 300 random points was too many for the study site size. As suggested in Nagel and Yuan (2016) and Congalton and Green (2009), a set of 300 random testing samples were created which yielded an average of 50 samples for each land-cover class. The study site for Nagel and Yuan (2016) was the Twin Cities Metropolitan Area which is 1,902,711 acres and is nearly 200 times larger than the area at the Tensleep Preserve.

Furthermore, there were regions on the preserve where GPS data was not collected due to the remoteness of these areas and these areas were excluded. The land cover was not documented with the collection of GPS polygons therefore training data was only created for the obvious land
cover types for these isolated regions. The GPS collected ground truthing data was used as a reference for creating training polygons. Once the ground truthing data inputted as training data, the polygon was traced and saved into the land cover type vector file.

Standard accuracy matrices were generated for both the 1989 and 2012 supervised classification images along with the users and producers accuracy and, overall accuracy. Then the Kappa accuracy was derived from the matrices (Cohen 1960; Congalton and Mead 1983; Congalton 1991). The error matrix is a square array of rows and columns that express the number of cells assigned to a particular land cover type relative to the actual land cover known as the reference data (Congalton and Mead 1983). The user’s accuracy is the total number of correct pixels in a single category divided by the total number of pixels that were classified in that category. The result is a measure of commission error (Congalton 1991). The producer’s accuracy, or error of omission represents error when the reference pixel that should have been assigned to a certain class value but was not represented in that class (Congalton 1991). The Cohen’s Kappa coefficient was first developed for Psychological studies (Cohen 1960) and is referred to as “inter-observer agreement.” According to Congalton and Mead (1983), the Kappa coefficient estimates the difference between the observed agreement between two maps and the agreement that might be attained solely by chance (Campbell 2002).

3.9 Feature Analyst Settings

3.9.1 1989 Training Polygons

The 1989 training data was composed from a combination of the GPS data collection and visual interpretation from personal experience at the preserve. The GPS data is obviously not an in situ representation because no data was collected in 1989 however visual interpretation was used to determine the land cover. Utilizing the collected GPS data as a reference along with
personal experience on the preserve and photograph interpretation, land cover classes were digitized to setup the supervised classification in Feature Analyst. The 1989 stacked image provided visually acceptable interpretation for the digitization of the different land cover types at the Tensleep Preserve. Furthermore, pictures taken from research and personal experience were used as a reference to determine if the land cover type was accurate for the 1989 image. A total of 137 polygons were created to represent the ten different land cover types for the Feature Analyst setup.
Figure 3.2. Training polygons of 1989 land cover types.
3.9.2 2012 Training Polygons

The 2012 training data used a combination of the GPS collected data and visual interpretation of the aerial photograph with personal experience at the preserve. The GPS collected data was completed in 2013 therefore the land cover types should be similar because land cover change would be minimal in only one year time. Therefore, the GPS collected data and photographs collected aided the training polygons for the 2012 supervised classification in the Feature Analyst setup. A total of 273 different polygons were created to represent the ten land cover types for the 2012.
Figure 3.3. Training polygons of 2012 land cover types.
3.9.3 Feature Analyst Supervised Learning

The flow chart (Figure 3.4) shows the work flow and processes used leading to the post classification comparison image. These are important steps to assure that the Feature Analyst supervised classification can produce adequate results, which leads to the post-classification comparison.

Natural feature was selected for the feature selector, this was completed for both images because the training data selected was ten different types of land covers. The input bands were selected for each image including all bands, and a texture layer was also selected to enhance the supervised classification. The input representation for each was different because the resolution quality of each image was also different. The input representation pre-defined foveal was used with the pattern width cell size of three for the 1989 image (Figure 3.5). While the 2012 image also used a pre-defined foveal but with a pattern width of nine cells (Figure 3.6).

Figure 3.4. Flow chart process for extracting land cover changes at the Tensleep Preserve.
Figure 3.5. Input Representation for the 1989 NAPP/Landsat 5 TM 3.71-m image.

Figure 3.6. Input representation for the 2012 NAIP 1-m image.
4. Results

4.1 Land cover classification

Land cover classification was determined and analyzed for the entire Tensleep Preserve study area for both 1989 and 2012. Table 4.1 displays the individual area of each land cover class and total values for each year. The largest land cover class in the 1989 study area was juniper pine which had a total area of 2012.43 acres or 19.95% of the entire study area. This was followed by rock cover (1,658.91 acres, 16.44%), grassland (1,250 acres, 12.39%), sagebrush (1,193.59 acres, 11.83%), lodgepole pine (1,109.81 acres, 11.00%), ponderosa pine (97.40 acres, 9.64%), bare land (748.48 acres, 7.42%), dirt road (562.28 acres, 5.57%), creek deciduous (537.52 acres, 5.33%), and the smallest class from the 1989 land cover was agriculture field (42.80 acres, 0.42%).

The largest land cover class in the 2012 study area was bare land with a total area of 1735.55 acres or 17.20% of the entire study area. This was followed by juniper pine (1,635.66 acres, 16.31%), creek deciduous (1,538.92 acres, 15.25%), sagebrush (1,377.40 acres, 13.65%), Lodgepole pine, (1,329.76 acres, 13.18%), ponderosa pine (1,018.36 acres, 10.09%), dirt road (705.10 acres, 6.99%), grassland (393.91 acres, 3.90%), rock cover (314.39 acres, 3.12%), and the smallest class from the 2012 land cover was agriculture field (39.25 acres, 0.39%).

The final 3.71-m land cover supervised classification map from 1989 is shown in Figure 4.1. The entire study area covers 10,088 acres therefore the entire preserve can be shown in detail at a high scale reference. The use of GPS derived training data with Feature Analyst successfully generated the land cover types at the Tensleep Preserve. There were difficulties with the separation of certain similar classes such as dirt roads, bare land and rock. These land
cover features have similar spectral signatures and the methods used in this study incorrectly classified land cover between these three land cover types. Furthermore, some coniferous species on the preserve were not initially correctly classified. Ponderosa pine and lodgepole pine have similar spectral signatures within the 1989 nine layer image. After processing, the software effectively accomplished the supervised classification using the ground truthed training polygons to classify very spectrally similar land cover types. The 1989 classified image produced a relatively satisfactory separation of land cover classes especially considering that the quality of the nine layer image included a three layer aerial photograph and a six layer Landsat scene. Some land cover types however were either overly represented or underrepresented. Agriculture field, for example, which is only located in the southwestern area on the map, was also misclassified in other areas. This overrepresentation was probably the result of vegetation near the creeks having vigor and health. The pixel representation of healthy vegetation (similar to the health of the vegetation represented within the agriculture field) is unique because there is only one section on the preserve where agriculture land is present. Juniper pine is also over represented in the 1989 classification image due to the spectral signature within the training polygons and the 1989 fused image. The nine layer image includes a three layer (RGB) mosaic of five different NAPP scenes taken at the same times, but there are noticeable differences between the images. The training polygons on one scene representing juniper pines have different spectral signatures than the juniper pines from a different scene from the same mosaic image.

The final 2012 1-m land cover supervised classification image is shown in Figure 4.2. The entire image is able to be shown in detail because the study area is relatively small. Despite issues noted above, FA was able to separate the different land cover types at the Tensleep
Preserve. As compared to the aerial photograph, results clearly differentiate the different land cover types, especially the grassland, sagebrush and agriculture field classes. The 1-m resolution of the aerial photograph provided much detail within each training polygon for the extraction process and enabled FA to perform the extraction well. As compared to the 1989 image, FA could process more pixels within each training polygon on the 2012 image. The Feature Analyst was able to process a 9 pixel width while the 1989 image was only able to process a 3 pixel width.

Table 4.1. 1989 and 2012 land cover classification results.

<table>
<thead>
<tr>
<th>CLASS NAME</th>
<th>1989 Acres</th>
<th>1989 Percentage</th>
<th>2012 Acres</th>
<th>2012 Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGRICULTURE</td>
<td>42.80</td>
<td>0.42</td>
<td>39.25</td>
<td>0.39</td>
</tr>
<tr>
<td>JUNIPER PINE</td>
<td>2012.43</td>
<td>19.95</td>
<td>1635.66</td>
<td>16.21</td>
</tr>
<tr>
<td>LODGEPOLE PINE</td>
<td>1109.81</td>
<td>11.00</td>
<td>1329.76</td>
<td>13.18</td>
</tr>
<tr>
<td>PONDEROSA PINE</td>
<td>972.40</td>
<td>9.64</td>
<td>1018.36</td>
<td>10.09</td>
</tr>
<tr>
<td>ROCK</td>
<td>1658.91</td>
<td>16.44</td>
<td>314.39</td>
<td>3.12</td>
</tr>
<tr>
<td>BARE LAND</td>
<td>748.48</td>
<td>7.42</td>
<td>1735.55</td>
<td>17.20</td>
</tr>
<tr>
<td>SAGEBRUSH</td>
<td>1193.59</td>
<td>11.83</td>
<td>1377.40</td>
<td>13.65</td>
</tr>
<tr>
<td>DIRT ROAD</td>
<td>562.28</td>
<td>5.57</td>
<td>705.10</td>
<td>6.99</td>
</tr>
<tr>
<td>GRASSLAND</td>
<td>1250.15</td>
<td>12.39</td>
<td>1538.92</td>
<td>15.25</td>
</tr>
<tr>
<td>CREEK DECIDUOUS</td>
<td>537.52</td>
<td>5.33</td>
<td>393.91</td>
<td>3.90</td>
</tr>
<tr>
<td>TOTAL</td>
<td>10088.37</td>
<td>100</td>
<td>10088.30</td>
<td>100</td>
</tr>
</tbody>
</table>
Figure 4.1. 1989 land cover classification map.
Figure 4.2. 2012 land cover classification map.
4.2 Interpretation of Land Cover by Classification Type: 1989

These areas are shown on Figures 4.3-4.12.

Sagebrush

The majority of the sagebrush cover was at the northern most area of the preserve. This region is at the highest elevation on the preserve and this land cover surrounds Canyon Creek which sinks underground near this area. The northern region of the preserve holds less drastic topography and has a more gradual gradient than other areas south on the preserve.

Figure 4.3. 1989 distribution of sagebrush land cover.
Rock

The rock cover in the supervised classification covers 1,658 acres and is represented along the northern areas of the study area. This representation is accurate because the rock land cover is mostly located on the south facing slopes and has a severe gradient where vegetation is not able to sustain life. These areas have large boulders and cliffs where the severe slopes also do not have the structure to sustain substantial amounts of plant life. The rock land cover is also prevalent following the creek valley and at the north end of the preserve. Some areas of rock cover include the cliff edges along the creek valleys on the south facing slopes.

Figure 4.4. 1989 distribution of rock land cover.
Ponderosa Pine

Ponderosa pine land cover is located along the creek valleys and exhibits patches at the southeastern region of the preserve. The largest patches are located above the valleys following the southern rim of the creeks while scattered spots along the creek valleys north and south of Cook’s Vee at the center of the lower part of the preserve. The obvious misclassification area can be found on the perimeter of the agriculture land cover at the southwestern region. It is unclear why Feature Analyst extracted ponderosa pine from this area because there is none present and there were no ponderosa pine training polygons either. This misclassification will affect the post classification comparison because the 2012 supervised classification image may not represent ponderosa pine in this area.
Figure 4.5. 1989 distribution of ponderosa pine land cover.

Lodgepole Pine

Lodgepole pine is represented in the 1989 classified image mainly following the western, north central and southwestern area of the creek valleys. The Lodgepole pine land cover classification is predominately along the north facing slopes within these valleys. In the central north region of the preserve lodgepole pines cover each steep valley where the slopes have eroded over time. This land cover consists of thick patches and appear dark on the 1989 classified image.
Figure 4.6. 1989 distribution of lodgepole pine land cover.

Juniper Pine

The Juniper pine supervised classification on the preserve exhibits a pattern of high density especially located in the southwestern region of the study area. The heavy patterns of Juniper pine are located within the easement shown in Figure 4.7. Other patterns are located near the center of the study area where ravines leading to the creeks show gradual patches following the ravines leading up toward higher ground. Then the Juniper pine pattern decreases
toward the northeastern region and has nearly no representation in the northern most area in the study area.

Figure 4.7. 1989 distribution of juniper pine land cover.

Grassland

The grassland exhibits patterns throughout the study area that are mostly within the center of the Tensleep Preserve study area. The center region of the preserve exhibits the highest concentration and the densest patterns while other regions like the northern section contain areas of smaller patches. This area also shows where the dirt road is winding through Cook’s Vee.
The southwestern area of the preserve displays small patches of grassland land cover, this area displays more bare land and juniper pine cover which could are covers to the possibility of showing the grasslands in this area.

Figure 4.8. 1989 distribution of grassland land cover.

Dirt Road

There are areas on the preserve where the dirt roads display the correct patterns which are clearly marked as dirt roads that are winding connected paths. However, this land cover type is designated too often in the 1989 land cover map. This preserve has never had 562 acres of this
land cover type. The non-vegetative land cover types did not classify to an acceptable standard because the accuracy is low. Despite the low assessment, the rock land cover does exhibit accurate readings along the Canyon Creek valleys. This area consists of steep canyons scorched by sunlight from dusk until dawn, where the slopes are so severe that vegetation cannot take root.

Figure 4.9. 1989 distribution of dirt road land cover.

Creek Deciduous

The deciduous vegetation along the creeks are depicted well at the western and eastern regions, accurately showing patches that follow the creeks within the preserve. Other creek
deciduous regions that are well classified are near the center of the study area where Canyon Creek flows through the preserve from the north then filters east. Some patches are found at the perimeter of the agriculture field and at the eastern edges, these areas do not display agriculture fields in the 1989 classified image.

Figure 4.10. 1989 distribution of creek deciduous land cover.

Bare Land

The bare lands within the study area are shown on the classified image toward the west. This land cover type may have been misrepresented because many of the training polygons are
near the southwestern section of the study area. Similar to dirt roads and rock, this land cover type was clearly misrepresented and was mixed with the other two land cover types. The bare land class, considering the quality of the image, was represented fairly well. There should be more bare lands represented throughout the 1989 classified image, especially in the northern regions of the preserve. The problem with bare land classification is most likely due to the resemblances to other land cover types like rock or dirt roads.

Figure 4.11. 1989 distribution of bare land cover.
Agriculture

Located only in the southwestern region of the study area, the rectangular agriculture has approximately 43 acres in the 1989 supervised classification image while 39 acres are shown in the 2012 image. The shape of the agriculture is depicted well, showing a rectangular area which is the true area of this feature class. However, this land cover type was over-represented because the rich health of the agriculture is similar to that of other deciduous vegetation species near the creeks on the preserve. These creek deciduous areas are very similar in appearance to the agriculture patch on the preserve because the vegetation that follows the creek have nearly the same appearance and spectral signatures as the agriculture. The patches displayed on the eastern region are not agriculture fields, they are creek deciduous misclassified as agriculture.
Figure 4.12. 1989 distribution of agriculture land cover.
4.3 Interpretation of Land Cover by Classification Type: 2012

These areas are shown on Figures 4.13-4.22.

Sagebrush

The majority of the sagebrush land cover is located at the northern region of the preserve. There the largest patches are at the highest elevation on the preserve. Also, smaller patches are located at the western region above the creek valleys. Furthermore, there are concentrations of small patches scattered at the center and southwest regions of the preserve.

Figure 4.13. 2012 distribution of sagebrush land cover.
Rock

The rock land cover type is represented in the classification image at the western area of the study area. This region has Tensleep sandstone outcrops and rolling hills where there is no vegetation present. There are obvious rock formations along the northern rim of Canyon creek that are not represented in the classification image, however the bare land cover does cover this area.

Figure 4.14. 2012 distribution of rock land cover.
Ponderosa Pine

The distribution of Ponderosa pine land in the cover class is visible in patches that follow both Canyon Creek and Cooks Canyon. This land cover type also appears in scattered patches in the east center and north center of the study area. The distribution is also found along the rims of canyon ledges and within the small valleys leading to the low areas of the canyons. The distribution of ponderosa pine in 2012, unlike that shown on the 1989 supervised classification image, is not found on the perimeter of the agriculture patch at the southwest region on the preserve.

Figure 4.15. 2012 distribution of ponderosa pine land cover.
Lodgepole Pine

The spatial distribution of lodgepole pine is located within the slopes of the creeks on the preserve. The north facing slopes within Canyon Creek at the northern region has the highest concentration of lodgepole pines. Other patches are located at the eastern region of the study area that also follow creek valley along the north facing slopes.

Figure 4.16. 2012 distribution of lodgepole pine land cover.
Juniper Pine

The distribution of juniper pine follows the rims of the creek valleys and is sporadic throughout the center of the study area. Large patches of this land cover are found along the slopes leading to the creek valley at the Canyon Creek and Cook’s Canyon. Also, scattered distributed patches are located along the northern area of the lower portion of the study area. There are also some distribution of juniper pine within the agriculture field, but this is not an accurate representation of this land cover. The 2012 NAIP image displays a darker coloration where the juniper pine is inaccurately displayed on the classification image, this coloration is most likely the tracks from the irrigation center pivot used to water the crops.

Figure 4.17. 2012 distribution of juniper pine land cover.
Grassland

Grassland shows a distribution of patches at the center of the study area on Cook’s Vee, at the southern region, and scattered patches at the northern area. The distribution of this class is interesting because it is well distinguished from the dirt road in the center of the study area. It is easy to locate the dirt road in this area because this land cover type boarders closely to it making it easy to tell where the route runs over the landscape.

![Figure 4.18. 2012 distribution of grassland land cover.](image)
Dirt Road

The distribution of the land cover type dirt road is grossly overestimated. This land cover is actually appears very little on the aerial photography, but it is inaccurately distributed throughout the land cover classification image. This is a result of the rock cover and bare land having similar spectral signatures to the dirt road, and the training data for this land cover being limited. However there are areas where the road land cover class is displayed correctly. These areas are located at the center of the preserve along Cook’s Vee, the far west region where dirt roads lead to other properties, the southern part of the study area and at the southeastern region where the entrance dirt road leads to the Tensleep Preserve main office. Furthermore, the circle driveway is depicted well. It is located near the main office in the southeastern region of the study area.
Figure 4.19. 2012 distribution of dirt road land cover.

Creek Deciduous

The distribution of the creek deciduous land cover does follow the creeks on the preserve, but in some coniferous areas this land cover is overestimated. These areas have vibrant and healthy vegetation which could have been why the classification results are inaccurate in those areas. The creek deciduous is located along Canyon Creek, Cook’s Canyon, Billy Creek, and at multiple areas at the northern regions of the preserve.
Bare Land

The distribution of bare land can be located throughout the study area. Large patches of bare land are located at the southwestern and northern regions of the preserve. This land cover at the northern region of the property displays the density well because these areas are neither rock nor dirt road land covers. Also, the bare land, dirt road and rock classes have similar spectral signatures because non exhibit vegetation cover, therefore making the differentiation of these land cover types difficult.
Figure 4.21. 2012 distribution of bare land cover.

Agriculture Field

The agriculture field land cover is most dense at the far west region of the preserve. This area is where a center pivot irrigated field is located and was the only area on the preserve used as the training data for this land cover type. The circular field shows gaps where the irrigation traction system rotates on tires, and around these gaps were misclassified as juniper pine in the 2012 land cover classification image. Furthermore, there are sporadic areas along the creeks where the agriculture field land cover type appears. This is most predominant at the creek area farthest
west on the preserve and at the creek confluence in the same region. This land cover also exhibits small patches along other creek valleys where creek deciduous are the likely correct land cover type. This inaccurate classification is most likely due to the richness and health of the creek deciduous vegetation which appears similar to the agriculture field on the NAIP aerial photograph.

Figure 4.22. 2012 distribution of agriculture field land cover.
4.4 Post-classification Comparison

The post-classification comparison was completed using ERDAS Imagine 2015 (Figure 4.23). The image matrix tool was used to input the 1989 supervised classification image as the ‘before image’ followed by the 2012 supervised classification as the ‘after image’. The resulting image will show the pixel changes or differences from each image, with ten different land cover types there will be a total of 100 different land cover change results. Each class is compared to one another at the pixel level, so though each image is at a different scale the results will compare the land cover types despite the different image resolutions. Table 4.2 shows the cross tabulation of the different land cover change types at the Tensleep Preserve from 1989 to 2012.
Figure 4.23. Post-classification Comparison results from the supervised classification 1989 (‘before image’) and the supervised classification 2012 (‘after image’).
Table 4.2. Cross tabulation of the land cover change at the Tensleep Preserve from 1989 to 2012.

<table>
<thead>
<tr>
<th>2012</th>
<th>Agriculture Field</th>
<th>Juniper Pine</th>
<th>Lodgepole Pine</th>
<th>Ponderosa Pine</th>
<th>Rock</th>
<th>Bare Land</th>
<th>Sagebrush</th>
<th>Dirt Road</th>
<th>Grassland</th>
<th>Creek Deciduous</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>23.21</td>
<td>1.06</td>
<td>0.16</td>
<td>3.34</td>
<td>1.00</td>
<td>0.30</td>
<td>0.10</td>
<td>3.24</td>
<td>3.28</td>
<td>3.56</td>
<td>39.25</td>
</tr>
<tr>
<td></td>
<td>3.59</td>
<td>465.46</td>
<td>28.94</td>
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<td>383.87</td>
<td>53.22</td>
<td>60.17</td>
<td>120.24</td>
<td>207.58</td>
<td>92.95</td>
<td>1635.65</td>
</tr>
<tr>
<td></td>
<td>0.16</td>
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<td>0.08</td>
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<td>8.59</td>
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<td>172.02</td>
<td>267.13</td>
<td>157.20</td>
<td>3.50</td>
<td>30.17</td>
<td>43.16</td>
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<td>62.93</td>
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<td></td>
<td>1.09</td>
<td>81.71</td>
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<td>19.73</td>
<td>14.94</td>
<td>130.50</td>
<td>2.71</td>
<td>43.62</td>
<td>16.96</td>
<td>2.56</td>
<td>314.37</td>
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<tr>
<td></td>
<td>5.43</td>
<td>508.73</td>
<td>6.47</td>
<td>74.56</td>
<td>358.24</td>
<td>284.26</td>
<td>122.55</td>
<td>115.23</td>
<td>191.55</td>
<td>68.50</td>
<td>1735.52</td>
</tr>
<tr>
<td></td>
<td>1.07</td>
<td>231.03</td>
<td>7.69</td>
<td>62.48</td>
<td>191.23</td>
<td>40.25</td>
<td>602.05</td>
<td>50.18</td>
<td>159.34</td>
<td>31.84</td>
<td>1377.75</td>
</tr>
<tr>
<td></td>
<td>1.60</td>
<td>178.65</td>
<td>0.57</td>
<td>28.62</td>
<td>200.42</td>
<td>157.43</td>
<td>25.90</td>
<td>47.75</td>
<td>16.60</td>
<td>705.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.26</td>
<td>342.21</td>
<td>2.63</td>
<td>82.54</td>
<td>171.50</td>
<td>78.87</td>
<td>241.69</td>
<td>118.06</td>
<td>441.94</td>
<td>53.22</td>
<td>1538.92</td>
</tr>
<tr>
<td></td>
<td>0.15</td>
<td>15.75</td>
<td>93.75</td>
<td>81.66</td>
<td>67.63</td>
<td>0.33</td>
<td>20.22</td>
<td>11.68</td>
<td>23.29</td>
<td>78.75</td>
<td>393.21</td>
</tr>
<tr>
<td>Total</td>
<td>43.43</td>
<td>2005.69</td>
<td>1109.74</td>
<td>972.27</td>
<td>1658.60</td>
<td>748.74</td>
<td>1193.74</td>
<td>561.75</td>
<td>1250.88</td>
<td>537.61</td>
<td>10082.45</td>
</tr>
</tbody>
</table>

The largest unchanged land cover from 1989 to 2012 is lodgepole pine at 796.96 acres. The largest area from this analysis is at the northern region on the preserve on the north facing slopes. The second largest area of unchanged land cover is sagebrush at 602.05 acres with the largest percentage of this analysis can also be found at the northern region on the preserve. The unchanged sagebrush is located upon the rolling hills in this rarely disturbed area. The third largest unchanged land cover is juniper pine at 465.46 acres with the largest proportion of this analysis is found at the west central and western regions on the preserve. The fourth largest unchanged land cover is grassland at 441.94 acres where the largest proportion of this analysis is located at the center of the preserve on the Cook’s Vee area. The fifth largest unchanged land cover is bare land at 284.26 acres with the largest proportion of the analysis found within the easement at the southwestern region of the preserve. The sixth largest unchanged land cover is
ponderosa pine at 267.13 acres with the largest proportion found in Cook’s and Canyon creek along with the southeastern region of the study area.

The largest land cover change was juniper pine to bare land which had a change of 508.73 acres with the largest proportion found at the southwestern region on the study area. The second largest land cover change is rock to juniper pine which had a change of 383.87 acres with the largest areas found at the northern regions of the lower section on the preserve. The third largest land cover change is rock to bare land at 358.24 acres with the largest proportion of this analysis found at the northern region of the study area. The fourth largest land cover change is juniper pine to grassland with a change of 342.31 acres from 1989 to 2012 and the largest proportion found at the southwestern region of the preserve. The fifth largest land cover change is sagebrush to grassland which had a change of 241.69 and the largest proportion found at the northern region of the study area. The sixth largest land cover change is juniper pine to sagebrush with a change of 231.03 acres and the largest areas found at the western region of the preserve on Cook’s Vee and the easement. The seventh largest land cover change is ponderosa pine to juniper pine which has a change of 219.63 acres with the largest proportions found within the creek valley and ravines at Cook’s canyon and Canyon Creek. The eighth largest land cover change is grassland to juniper pine which had a change of 207.58 acres with the largest proportion found at the center of the study are on Cook’s Vee.

4.4.1 Post-classification Comparison Image Accuracy

The accuracy assessment results from the 1989 and 2012 images were 77% and 85% respectively. Therefore, the post-classification comparison image created from comparing the two images has an accuracy of 65.45%. This is determined by the combination of the accuracies from both the 1989 before image (77%) and the 2012 after image (85%) which results in the
65.45% accuracy of the post-classification comparison image using the two layer merger operation Union Matrix process in ERDAS Imagine 2015. With ten land cover classes there were 100 different land cover change possibilities including no change results. The post-classification comparison image displays the possible changes of land cover at the preserve.

4.5 Tensleep Preserve Easement

The easement is located at the southwestern region of the preserve and is monitored by the Tensleep Preserve land manager. The easement has different regulations than the other areas on the preserve. For example, there may be a certain degree of ecological monitoring required by management, or an agreement to allow domestic animals on the property, and restrictions for development on the land while the exact restrictions for the Tensleep Preserve easement is unknown, common easement restrictions are designed to uphold the land value as so by reducing environmentally harmful actions. The largest land cover change is juniper pine to bare land which is located at the center region of the easement. This change is expected because it is also the largest change on the entire preserve and the 1989 supervised classification showed this area with large patches of juniper pine, while the 2012 supervised image showed bare land in this area within the easement.

The two most significant land cover changes that occurred on the easement are: juniper pine to bare land and juniper pine to grassland. The juniper pine to bare land (203.57 acres) is the most land cover change on the easement. This large area of change is due from the overestimation of land cover in the 1989 classified image and the accurate estimation of the land cover in the 2012. However, this change analysis can provide specific areas on the easement where management may want to monitor more than others. This can reduce travel time and assist with future easement monitoring projects or assessments.
The second highest land cover change within the easement is juniper pine to grassland (95.72 acres). This change scope is small, hardly noticeable when looking at the post-classification image (Figure 4.23) and the easement comparison image (Figure 5.3). This is another testament to the constant monitoring and current situation of how little the land cover on the easement has not changed over the past twenty-one years. The largest patches are located at the western areas of the easement. As previously described, juniper pines can be difficult to extract because some individual plants are surrounded by bare land.

4.6 GPS Data Differential Correction

The differential correction to the collected GPS truthing data was completed by post-processing using GPS Pathfinder Office. There were three separate files with a collection of different vector files which needed correction because files within the Trimble Juno GPS unit had a data capacity restriction. Once a data file was filled to capacity, the Trimble Juno GPS unit prompted the file was full and a new data file was created to continue data collection. The created data dictionary for the Tensleep Preserve data collection was used with each new file. The base station in Tensleep, Wyoming was used for the differential correction for each of the three data files. The Tensleep base station code is, CORS, TENSLEEPRWY2005 (P033) and is at a distance of 1.20 miles from the Tensleep Preserve in Ten Sleep, Wyoming. This was the closest base station found from the study area.

4.6.1 Post Processing GPS Truthing Data

Trimble file one was completed with 99.72% of data files corrected and 63.86% of the data was corrected to 2-5 meters. File two was completed with 99.95% of data files corrected and 48.38% of that data was corrected to less than 5 meters, 37.05% to 2-5 meters, and 14.55%
to 1-2 meters. File three was completed with 99.99% of data files corrected and 39.04% of that data was corrected to 2-5 meters, 38.94% to less than 5 meters, and 21.22% to 1-2 meters.

4.7 Non-vegetation

The non-vegetation land cover classes had some inconsistency between the two years. The 1989 supervised classification has rock cover (1658.91 acres) as the highest while the 2012 supervised classification results has bare land (1735.55 acres) as the highest non-vegetation land cover (Figure 4.24). The large difference of area cover between these years is most likely a result from these land cover types having similar spectral signatures. For example, the rock land cover type is high in the 1989 supervised classification image while bare land is high in the 2012 supervised classification image; therefore, the land cover types having similar spectral and textural signatures resulted in mixed classes between the two images. This result will affect the post-classification comparison that would show a substantial change from rock to bare land. Furthermore, the accuracy assessment of these images including the post-classification comparison image will be greatly affected by the non-vegetation class similarities in shape and structure and inconsistencies from the supervised classification images. It is important to point out these inaccuracies because they have significantly affected the accuracy assessment.
Figure 4.24. Non-vegetation (bare land, rock, and dirt road) at the Tensleep Preserve in 1989 and 2012 over a digital elevation map and hillshade image.
4.8  Accuracy Assessment

The overall accuracy of the 1989 classified image is 77% with a Kappa accuracy of 74% (Table 4.3). The lower accuracy was expected for this image primarily because similarities in land cover makes class separation difficult. First, the resolution quality of the nine band image is 3.71 meters which could result in some mixed pixel results. For example, the width of the dirt roads on the preserve are about the same as the width of a car. Therefore, when rock or bare land cover types are adjacent to the dirt road, the 3.71 m resolution may be too large to accurately separate the differences. Each pixel size is about 12 feet square which is larger than the width of the dirt road. Second, the classifications of dirt road, bare land and rock land cover types have similar spectral signatures causing the classification of these classes to be classified incorrectly. These classes had the greatest amount of confusion, this is likely due to the fact that the dirt road, bare land and rock land cover types are spectrally comparable and their individual class shapes and textures are nearly indistinguishable. Throughout the accuracy assessment process different land cover types which are bare land were classified as dirt roads or rock. These results lowered the overall accuracy assessment because the Feature Analyst classifier software was not capable of separating the similarities between these three non-vegetative land cover types. Finally, the creek deciduous and agriculture field classes were over represented in the 1989 supervised classification image. The creek deciduous exhibited patches within areas that were lodgepole pine and ponderosa pine. The agriculture field displayed patches in regions that are lodgepole pine regions especially following Canyon Creek on the north facing slopes. These issues resulted the 1989 supervised classification image to have a low user’s and producer’s accuracy and also lowered the overall accuracy assessment. The user’s accuracy for dirt road is 22%, followed by rock at 70%, then bare land at 75%. The producer’s accuracy for dirt road is 40%,
followed by bare land at 55%, then rock is 77%. The separation of the different non-vegetative land cover classes was not completed because the goal of this research was to use the original truthing data to assess how well Feature Analyst could distinguish the land cover types on the preserve.

The overall accuracy of the 2012 classification land cover image is 84.5% with a Kappa accuracy of 82% (Table 4.4). The overall accuracy is higher than the 1989 land cover classification, which is to be expected because the resolution of the 2012 image is one meter compared to the 1989 land cover image which is 3.71 m. The higher resolution 2012 image has more pixels overall therefore each land cover type training data polygons contain more pixels than the 1989 image. The more the representation of information within each polygon pixels the better quality of the supervised classification image. The 2012 image only has three layers as opposed to the 1989 image which has a total of 9 layers however the 1989 image has a resolution is 3.71 m. There were six land cover classes which have a producer’s accuracy above ninety percent, these classes are: agriculture field (100%), juniper pine (97%), sagebrush (92%), dirt road (100%), grassland (97%) and creek deciduous (100%). These classes display accurate representation of true land cover types at the Tensleep Preserve. Also, the classes have high accuracy in the 2012 supervised classification because they either have well defined training polygons and/or the reference total is relatively low. For example, creek deciduous only has three reference totals and a total of eight classified resulting in the user’s accuracy to be 38%. However the three referenced random points used for the accuracy assessment were classified correctly.

The classes with the lowest accuracy in the 2012 supervised classification image are similar to that of the 1989 supervised classification, which are dirt road, bare land and rock. The
dirt road user's accuracy is 22.22%, while bare land has a 75%, and rock is at 69.70% (Table 4.3). While the producer's accuracy for dirt road is 40%, bare land is at 54.55%, and rock at 76.67% (Table 4.3). These classes are spectrally comparable and have shapes and textures that are also similar which makes distinguishing their differences difficult when the training polygons used to extract these classes have shared characteristics. Furthermore, the dirt road, bare land, and rock classes also are similar in their texture and shape.

4.8.1 Cross-tabulation

Table 4.3. Accuracy matrix for 1989 land cover map.

<table>
<thead>
<tr>
<th>Class</th>
<th>Agriculture</th>
<th>Juniper Pine</th>
<th>Lodgepole Pine</th>
<th>Ponderosa Pine</th>
<th>Rock</th>
<th>Bare Land</th>
<th>Sagebrush</th>
<th>Dirt Road</th>
<th>Grassland</th>
<th>Creek Deciduous</th>
<th>Grand Total</th>
<th>User's (Commission)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Juniper Pine</td>
<td>0</td>
<td>37</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>43</td>
<td>86.05%</td>
</tr>
<tr>
<td>Lodgepole Pine</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>17</td>
<td>88.24%</td>
</tr>
<tr>
<td>Ponderosa Pine</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>12</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>17</td>
<td>76.59%</td>
</tr>
<tr>
<td>Rock</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>25</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>33</td>
<td>69.70%</td>
</tr>
<tr>
<td>Bare Land</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>12</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>16</td>
<td>75%</td>
</tr>
<tr>
<td>Sagebrush</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>88%</td>
</tr>
<tr>
<td>Dirt Road</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>22.22%</td>
</tr>
<tr>
<td>Grassland</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>19</td>
<td>0</td>
<td>24</td>
<td>78.17%</td>
</tr>
<tr>
<td>Creek Deciduous</td>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>75%</td>
</tr>
<tr>
<td>Grand Total</td>
<td>3</td>
<td>40</td>
<td>21</td>
<td>15</td>
<td>30</td>
<td>22</td>
<td>32</td>
<td>5</td>
<td>22</td>
<td>10</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Producer’s (Omission)</td>
<td>100%</td>
<td>92.50%</td>
<td>71.13%</td>
<td>10%</td>
<td>76.67%</td>
<td>54.55%</td>
<td>60.75%</td>
<td>40%</td>
<td>86.36%</td>
<td>90%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall Accuracy</td>
<td>77.00%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kappa Accuracy</td>
<td>72.58%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Table 4.4. Accuracy matrix for 2012 land cover map.

<table>
<thead>
<tr>
<th>2012</th>
<th>Agriculture Field</th>
<th>Juniper Pine</th>
<th>Lodgepole Pine</th>
<th>Ponderosa Pine</th>
<th>Rock</th>
<th>Bare Land</th>
<th>Sagebrush</th>
<th>Dirt Road</th>
<th>Grassland</th>
<th>Creek Deciduous</th>
<th>Grand Total Use's (Commission)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>100%</td>
</tr>
<tr>
<td>Juniper Pine</td>
<td>0</td>
<td>30</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>37</td>
<td>81.08%</td>
</tr>
<tr>
<td>Lodgepole Pine</td>
<td>0</td>
<td>0</td>
<td>26</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>27</td>
<td>96.90%</td>
</tr>
<tr>
<td>Ponderosa Pine</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>19</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>21</td>
<td>90.48%</td>
</tr>
<tr>
<td>Rock</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>50.00%</td>
</tr>
<tr>
<td>Bare Land</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>29</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>32</td>
<td>90.63%</td>
</tr>
<tr>
<td>Sagebrush</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>23</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>24</td>
<td>95.89%</td>
</tr>
<tr>
<td>Dirt Road</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>9</td>
<td>22.22%</td>
</tr>
<tr>
<td>Grassland</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>32</td>
<td>0</td>
<td>34</td>
<td>94.12%</td>
</tr>
<tr>
<td>Creek Deciduous</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>37.50%</td>
</tr>
<tr>
<td>Grand Total</td>
<td>2</td>
<td>31</td>
<td>31</td>
<td>22</td>
<td>8</td>
<td>43</td>
<td>25</td>
<td>3</td>
<td>3</td>
<td>200</td>
<td>100%</td>
</tr>
</tbody>
</table>

| Producer's (Omission) | 100% | 96.77% | 83.37% | 86.56% | 37.50% | 67.44% | 92.00% | 100% | 96.97% | 100% |
|
| Overall Accuracy     | 84.50% |        |        |        |        |        |        |      |        |      |
| Kappa Accuracy       | 81.90% |        |        |        |        |        |        |      |        |      |
5. Discussion

5.1 Land Cover Classification Distribution and Patterns

Tensleep Preserve resides on the foothills on the southwestern side of the Big Horn Mountains in North Central Wyoming. This region and the surrounding area have been occupied by humans for thousands of years. The topography is incredibly diverse with the creeks carving valleys and gorges, Tensleep sandstone rock formations and steep canyon cliffs. Each of these areas have a different microclimate and ecosystems because even though the proximity is near, the change in elevation affects the land cover for each drastically. This unique property holds a diverse mix of land cover that includes grasslands, shrubs, bare land, ponderosa pines, and bare rock formations at high elevations. The lower elevations such as the canyons have a different mix of land cover that includes limber pines, deciduous trees, and also rock formations. Canyon Creek, which carved the main canyon through the preserve, runs through the property from the north and meanders west at the lower region of the property. One land cover that was not able to be represented well in this study are the steep cliffs that the creeks carved over time. Some of cliffs have a 500 feet drop and many avian species and bats find a niche on these cliff sides. This unique land cover was not able to be mapped because the research used aerial photos for interpretation and extraction of the different land cover types. These cliffs are vertical from the aerial photographs which are unable to be mapped because the angle of this unique land cover is not visible with the data sets allocated for this research. The cliffs are a great area for possible research topic for avian or bat scientists.

The land cover distribution results are as expected because the ten land cover types discussed in this study were all represented throughout the preserve and are located at the expected places on the preserve. The total land cover from each year is also represented well.
because each match with the original merged image (1989) and aerial photograph (2012). There are some areas where certain land cover types were either misclassified or over represented but overall the 77% and 85% accuracy assessments for the 1989 and 2012 land cover images are nearly acceptable and acceptable respectively in terms of statistical standard. The GPS truthing data collection definitely aided the creating of accurate training polygons for the creation of the two supervised classification images. Without the GPS truthing data separating the differences between the similar land cover types, this level of accuracy would have been nearly impossible. The truthing data polygons also aided the creation of training polygons for the input representation of the different land cover types for the Feature Analyst supervised classification images for both 1989 and 2012.

Despite the lower accuracy when compared to other studies of similar contexts, the separation of comparable land cover types in this research is satisfactory because the results provide valuable information for preservation purposes. The Tensleep Preserve manager can use this information for restoration projects to identify high risk areas, and to design future scientific projects. The 1989 land cover image did not meet the requirements stated in the objectives for this research because an overall accuracy of 85% or higher is considered scientifically accepted and effective for analysis. The image and analysis can still be useful as a baseline study and referenced for questions about the historical land cover.

The 1989 supervised classification is, therefore, a null result because the accuracy assessment of the image is below 85%. The difficulties with the 1989 land cover image resulted from the quality of data within the image. The number of training polygons used is low because the visual interpretation was more difficult than the 2012 1-m NAIP image. There was much uncertainty amongst the land cover classes, especially the non-vegetation land covers, because
the image quality was low. Overall, the FA object-based feature extraction software did well separating and extracting the different land cover types. The GPS collected truthing data is a necessary component for this because training data would not have been as abundant or as accurate without the truthing data. However, the land cover types that have similar spectral and textural signatures had some results that were misclassified. To compensate for the lack of quality data for the 1989 NAPP image additional data layers were acquired to improve the amount of detectable information. To minimize the similarities of the different land covers addition layers were added to the original 1989 NAPP aerial photography to enhance information for the extraction process.

The 2012 supervised classification is an acceptable result because it has an accuracy of 85%. This is an acceptable result because it is at the required 85%. This aerial photograph having a 1-meter resolution greatly attributed to the acceptable result and high quality of the supervised image. It is also recommended that any further studies on the land cover change in this area use similar resolution as to compare those results with the 2012 supervised classification in this study.

The research goal was to provide an accurate assessment of the land cover change that occurred at the Tensleep Preserve from 1989 to 2012. The separate classification images, 1989 and 2012, can give the land manager a visual tool to assess the differences between those years. The post-classification comparison map highlights both the significant changes of land cover on the property and the unchanged areas. These highlights can then be further examined by the manager to determine the cause or inquire more information and possible restoration action. The land manager can make executive decisions to determine if these are areas that would need ecological restoration or he may already have the knowledge of the occurrence in a specific area.
In that case, the post-classification map would assist with the size of the change and further assist with any future restoration projects which would attempt to restore the native vegetation. A possible example of change that would not show on the post classification comparison map would be the addition of invasive species such as cheatgrass (*Bromus tectorum*) or houndstongue (*Cynoglossum officinale*). These invasive species or noxious weeds are present at the preserve but the areas were either too small to map or were underneath other vegetation. For example, cheatgrass patches were found in abundance underneath ponderosa pines therefore were unable to be classified because the aerial photograph would only have shown the ponderosa pine cover. Houndstongue on the other hand, can be found in open areas mixed in with a variety of other vegetation such as grasslands, sagebrush and junipers. Like cheatgrass, houndstongue forms monocultures that can overtake areas and out produce other native vegetation which are endemic to the area. Allocating these areas with invasive species present is important to the management of the Tensleep Preserve because these areas can become overtaken quickly. Restoration projects can combat the progression of cheatgrass and houndstongue to keep the native vegetation present and healthy in the Tensleep Preserve and beyond.

5.2 Research Implications

The preserve only has had two known ownerships before purchased by The Nature Conservancy in 1980. This area was first owned by a couple who herded sheep before it was owned by the Girl Scouts West. The Girl Scouts West used the property as a retreat getaway for horseback riding and outdoor recreation activities. The trails from these activities are still present on the preserve and are used as routes for animals and hiking trails for visitors. The Nature Conservancy recognized this property as having high biologic value and important plant
and animal species. Also, there are endemic plants on the preserve that are highly sensitive to environmental changes and rare bat species like the spotted bat that warrant further study.

The Tensleep Preserve has a mix of rangeland shrubs, coniferous pines, grasslands and canyons cover this unique and protected landscape. More than 9,000 acres are protected at the preserve, but this does not include the large amount of vertical canyon cliff walls which inhabit birds and many different species of bats. If a topological map were to be flattened, to include the canyon wall areas, the preserve would nearly double in size. Ungulates are able to travel on routes for safe migration, while raptors soar in search of prey, black bears are present but hardly seen, coyotes utilize the land for safety and marmots roam freely. The Tensleep Preserve could have future human settlement because the necessary infrastructure is present with power lines and roads. However, this region should have as little human impact as possible and that is what makes this area interesting and makes the work of the land manager Trey Davis essential to maintaining the preserve’s natural state.

5.3 Post-Classification Comparison

The post-classification comparison image has an accuracy of 65.45% and contains viable information for the land manager to interpret. This level of accuracy for this image was expected due to the resolution quality of the 1989 image, and can serve as a baseline for future land cover research on the preserve or other natural areas. The viable information is highlighted in the post-classification comparison above, this information can help the Tensleep Preserve staff isolate the areas on the preserve that are in need of restoration consideration or monitoring. For example, the land cover types with the most change can be evaluated and possibly have an explanation as to why these changes happened. Furthermore, there may not be a reasonable explanation, so future evaluation by the land manager would have to take place to determine the factors of
change. Highlighting these changes will help the management team pinpoint the location where land cover transitions are occurring and to identify causes for the changes. Also, the post-classification comparison image can highlight the areas on the preserve that have had little to no change. Locating these areas could help with other scientific organizations or universities to conduct research on the preserve to better understand conditions that promote land cover stability. Likewise, by reintroducing native plants or animals that are in areas where undesirable changes have occurred, managers may be able to restore disturbed areas and regain ecological balance in vulnerable areas.

This analysis of land cover in the Tensleep Preserve is considerably more accurate than the National Land Cover Database maps (U.S. Geological Survey (USGS), 2000 and 2014) from 1992 and 2011 National Land Cover Database of the Tensleep Preserve (Figures 5.1 and 5.2).
Figure 5.1. 1992 National Land Cover Database of the Tensleep Preserve compared to 1989 Feature Analyst land cover analysis.
Figure 5.2. 2011 National Land Cover Database of the Tensleep Preserve compared to 2012 Feature Analyst land cover analysis.
5.3.1 Unchanged Land Cover Types

The six unchanged land cover types with the largest cover area are: lodgepole pine, sagebrush, juniper pine, grassland, bare land, and ponderosa pine. Lodgepole pine shows the largest unchanged land cover type on the preserve from 1989 to 2012 at 796.96 acres. This is expected because this species dominates the north facing slopes in the undisturbed creek valleys.

While hiking Billy Creek during my internship in 2011, it was clear to see why the stands of lodgepole pines remain abundant. In some areas the sun does not touch the ground because the thick distribution of the lodgepole pines does not allow the light to penetrate on Earth’s surface.

The sagebrush was the second largest unchanged land cover type with 602.05 acres. It is assumed that this class is underestimated because many patches on the preserve went unnoticed. This arid plant could be easily confused with bare land during the FA process because the spectral structure, shape, and coloration of each are similar. Also, some individual sagebrush plants do not appear on the classifications because the mixed pixel was classified as bare ground or different non-vegetation land cover. The large patches at the northern area of the preserve are classified well, however the smaller patches on Cook’s Vee for example, are classified on the 2012 supervised classification image but do not show on the 1989 supervised classification image.

Juniper pine has the third highest unchanged land cover type with a total of 465.46 acres. Like sagebrush, the juniper pines classification can be confused with bare ground because the arid plants have spectral similarities. Also, single plants that stand alone and are surround by bare land or rock formations were occasionally not classified. This cause is likely the effect from the mixed pixel factor where the majority of the land cover within a pixel was non-vegetation therefore not accounting for the standalone juniper pine. Largely located on the
western area of the preserve, the unchanged juniper pines are in patches near the sub-creek valley which are adjacent ravines attached to Cook’s Creek.

The fourth largest unchanged land cover type is grassland which showed 441.94 acres of this land cover class. This unchanged land cover is found on and south of Cook’s Vee. This remaining land cover type is a great indicator for locating the different grassland species on the preserve. The grassland land cover includes all types of grass species in this region and were considered in this class but not separated. The distribution of unchanged grasslands are in large connected patches with other land covers like rocks and dirt roads in-between. These are intermittent areas the Tensleep Preserve staff may want to highlight because invasive plants can encroach upon areas like this and begin to spread.

Bare land is the fifth largest land cover type displaying unchanged cover with 284.26 acres of unchanged land. These patches are located at the lower elevations on the southwestern region of the preserve. This area has rolling hills where the Tensleep sandstone is visibly red. This unchanged land cover analysis can serve as a reference for future research to assess where bare land has remained for the past twenty-three years. This information can also be used for restoration projects because the perimeters can be evaluated and assessed as to the risk of further bare lands encroaching vegetative areas.

Ponderosa pines showed the sixth largest unchanged land cover type with 267.13 acres unchanged from 1989 to 2012. These trees are known to live for hundreds of years and can withstand fires. The statistical estimations of acreage from each year is similar when considering the spatial resolution difference of each image (1989: 972.40 acres, 2012: 1028.36 acres). Other than agriculture field, this is the closest statistical land cover change. This unchanged class is found along the lower creek valleys and in patches at the eastern areas of the preserve.
5.3.2 Change Land Cover Types

The eight largest land cover types that exhibited change from 1989 to 2012 are: juniper pine to bare land, rock to juniper pine, rock to bare land, juniper pine to grassland, sagebrush to grassland, juniper pine to sagebrush, ponderosa pine to juniper, and grassland to juniper pine.

The juniper pine land cover change to bare land (508.73 acres) can be a result from the low resolution quality of the 1989 merged image. The 1989 classification image showed an overestimation of juniper pines in the southwestern area on the preserve. While the 2012 image, which was more accurate, showed more bare land in the same area resulting in a large land cover change. Despite the overestimation, it is assumed that this land cover change is the largest on the preserve because many juniper pines likely have turned into ‘skeletons’ (dead juniper pines still standing). This change may be contributed to different factors such as climate change, invasive species or mechanical removal.

The land cover change rock to juniper pine (383.87 acres) is an interesting change because it is highly unlikely juniper pines expanded upon rock formations on the preserve. Therefore, similar to the juniper pine to bare land cover change, it is likely that this result is directly related to the low resolution quality of the 1989 classified image. However, this land cover change is an example of the juniper pine land cover that was not recognized by the 1989 merged image. This difference provides a detailed area where the juniper pine land cover was not registered in the ‘before image’ and this information could be valuable in future research at the preserve or other natural areas.

The third highest land cover change was rock to bare land (358.24 acres). There was much confusion between the three non-vegetation land cover types, as mentioned before, so this was a predictable change analysis because the bare land in the 2012 classification image was
much more than the 1989 image. Furthermore, the rock land cover was overestimated in the 1989 classified image resulting in the large land cover change results.

The juniper pine to grassland land cover change is the fourth highest (342.21 acres). This is valuable information because the causes of the increased grassland land cover could be a direct result of the juniper pine land cover loss while grassland encroached into these areas. These areas are also important because they could be vulnerable to invasive species because noxious weeds can out compete native grasses and form monocultures.

The fifth largest land cover change is sagebrush to grassland (241.69 acres). Largely located at the northern end of the study area, this change is likely caused by the overestimation of sagebrush in the 1989 classification image. The northern area of the preserve is rarely monitored by foot because of property restrictions therefore this analysis can serve as a baseline for future monitoring efforts. Similar to the loss of juniper pine to grassland, these areas may be vulnerable to invasive species encroachment, therefore a onetime monitoring session to confirm these changes would save time because the staff could directly hike to these specific areas.

The change from juniper to sagebrush is the sixth largest change (231.03 acres). Mostly located at the western region of the preserve, this change is unlikely because this research timeframe would not allow for it to occur. Sagebrush patches do not encroach upon juniper pines in a twenty-one year span, therefore it is highly probable that FA overestimated the juniper pine in the 1989 classified image while the 2012 classified image produced adequate results extracting the sagebrush land cover.

The seventh largest land cover change on the preserve is ponderosa pine to juniper (219.63 acres). Found on the slopes of creek valleys, this land cover change is an unlikely
analysis because of the time frame of the study. The 1989 classification image showed an overestimation of ponderosa pine land cover while the juniper pine was underestimated. Then, the 2012 classified image, which is more accurate, correctly classified juniper pines in areas that were ponderosa pines in the ‘before image’ during the post-classification comparison process. However, this analysis is a good indicator as to the misclassified juniper pine in the 1989 classified image and can be used as a reference for future analysis.

The eighth largest land cover change from the post-classification comparison analysis is grassland to juniper pine (207.58 acres). This land cover change is sporadic throughout the study area and found on flatland and creek valleys. Like other analyses, this change is unlikely considering the time frame of the study. The loss of grassland and the encroachment of juniper pines process would have taken longer than the 21 year span for this study. Therefore, it is predicted that the classification analysis of grassland in the 1989 classification image is overestimated while the juniper pine classification from the 2012 image is more accurate.

5.3.3 Non-vegetation Comparison

The non-vegetation on the preserve, dirt road, bare land and rock could have been combined into one class to prevent confusion between these classes (Figure 4.24). This combination would have improved the accuracy assessment results because the most confusion and absence of separation is found in the non-vegetation land cover types. However, the focus of this research is to utilize the GPS truthing data to aid the separation of land cover types at the Tensleep Preserve using FA, so these similar land cover types remained as single classes and were not combined. During the pre-processing of data selection other land cover types were not used because either there was not enough adequate data for representation or the aerial photographs did not display or show these land cover types for further processing.
5.4 Tensleep Preserve Easement

The easement at the Tensleep Preserve is located at the southwest region of the property and is included in this research of land cover change. The easement has certain restrictions that are in place to protect the ecological value and prevent development. It is important to monitor the changes of the easement because the idea of having an easement is to protect the land as is and to prevent future changes or development. The post-classification comparison of the easement is shown in Figure 5.3. The juniper to bare land change is the largest change of classes from 1989 to 2012. This estimation is overestimated because the 1989 supervised classification image overestimated the juniper in this area while the 2012 supervised classification image overestimated the bare land. The total area of change from juniper pine to bare land is 203.57 acres. The least amount of land cover change on the easement is bare land which has 153.77 acres remaining from 1989 to 2012. However, the change of non-vegetation, such as bare land to rock or rock to bare land, had the most confusion between classes.
Figure 5.3. Tensleep Preserve easement post-classification comparison and significant land cover changes.
5.5 Sagebrush Change Comparison

The change of sagebrush on the preserve from this research totals 591.69 acres however the sagebrush unchanged totals 602.05 acres (Figure 4.23 and Table 4.2). This land cover type, like juniper pine, can be difficult to classify because the texture and spectral signatures are similar to both juniper pine and possible bare land. It can be similar to bare land because the training polygons which only contained larger patches of each land cover type probably have some bare land within them. This results in a confusion of classifying because FA and this research purpose is to separate each land cover type as best as possible. However, despite the detailed methods used for this research there will some degree of uncertainty because each training polygon will never only contain the chosen land cover even though that was the attempt. This was a process to produce the best possible result using aerial photographs, GPS collected data and Feature Analyst object-based feature extraction.
6. Conclusion

6.1 Summary of methods and results

Three sets of data were produced in this study: two land cover maps and a post-classification comparison map. These maps were processed to show land cover types and the land cover changes for the entire study area, and statistical analysis for each of the three maps. Overall, this project was a success because the Feature Analyst object-based classification tool was able to identify and map rangeland land cover types. Utilizing GPS truthing data to aid the Feature Analyst process for producing supervised classified images also proved successful for rangeland classification. The land cover change analysis of the 1989 was below the predicted 85%, but this type of study has never been done in this area, so this research can serve as a baseline for future land cover analysis. Despite the low accuracy of the 1989 classified image, it still has great value because the image was the earliest available that included multiband data. The earlier photograph did not have spatial resolution and band specification to do this type of analysis.

The supervised land cover maps indicated that throughout the study area most of the land cover has remained the same from 1989 to 2012. This analysis focused on the changes of land cover change on the preserve, however substantial areas of the preserve has not has land cover changed in the past 21 years. This finding is a testament to the dedication of the Tensleep Preserve manager and staff has in maintaining and monitoring the land. One of the most valuable results from the study is that it can serve as a benchmark for future Tensleep Preserve land cover change analysis. This study can serve value to other similar studies in other natural areas or to this preserve in maybe another ten or twenty years.
This study’s time frame is too short to consider any significant effects of climate change that may have occurred between 1989 and 2012. Future studies, however, can utilize this land cover analysis for comparison over a longer period of time. Over the next half century, this method may also prove useful by providing a baseline of land cover as it existed in the late twentieth century and early twenty-first century. These kinds of large scale land cover change assessments will be useful if changes in precipitation and temperature begin to alter ecology of western rangelands. Furthermore, a possible future NDVI analysis could be beneficial for assessing the health of the vegetation at the preserve because it can provide detailed information of the semi-arid ecology of places similar to the Tensleep Preserve.

So while this thesis project demonstrated that the quality of aerial photography and remotely sensed data has integral limitations regarding the accuracy of temporal land cover analysis, it also indicates that this methodology can, in fact, produce useful rangeland management data to help conservationists better understand and cope with the long term effects of a changing climate.
Bibliography


